AD-A207 805

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

NAVAL AVIATION MAINTENANCE
DECISION SUPPORT SYSTEM

by

David L. Allen
and
William R. McSwain

March 1989

Thesis Advisor: M.J. McCaffrey

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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; Distribution is unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School — 6b OFFICE SYMBOL (If applicable): 54Mf	7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000	7b ADDRESS (City, State, and ZIP Code): Monterey, California 93943-5000
8a NAME OF FUNDING/SPONSORING ORGANIZATION — 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

NAVAL AVIATION MAINTENANCE DECISION SUPPORT SYSTEM

12 PERSONAL AUTHOR(S)

Allen, David L. and McSwain, William R.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM ______ TO ______	1989, March, 23	114

16 SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Aviation Maintenance Control, Decision Support System, Expert System; (KT)

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

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20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL: Martin J. McCaffrey	22b TELEPHONE (Include Area Code): 408-646-2488 — 22c OFFICE SYMBOL: 54Mf

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Approved for public release; distribution is unlimited.

Naval Aviation Maintenance Decision Support System

by

David L. Allen
Lieutenant Commander, United States Navy
B.A., Westmar College, 1977

and

William R. McSwain
Lieutenant, United States Navy
B.S., University of Kansas

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN INFORMATION SYSTEMS

from the

NAVAL POSTGRADUATE SCHOOL
March 1989

Authors: David L. Allen

William R. McSwain

Approved By: Martin J. McCaffrey, Thesis Advisor

Daniel R. Dolk, Second Reader

David R. Whipple, Chairman,
Department of Administrative Sciences

Kneale T. Marshall,
Dean of Information and Policy Sciences

ABSTRACT

This is a Decision Support/Expert System design proposal for the Naval Aviation Maintenance Control environment. A survey of contemporary literature concerning the use, development and implementation of such systems is conducted. A general examination of the decision maker's problem domain including the organization, requirements and constraints is presented. Design criteria are identified. An adaptive/prototype approach to design and system development is strongly recommended. Value analysis is suggested as the method for justification of the system. Specific recommendations for future development and implementation of the system are made.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

U.S. Naval Aviation is a leader in employment of sophisticated technology designed to reduce pilot workload and increase effectiveness of aircraft such as the F/A-18. An example of such technology is the aircraft's capability to acquire and track multiple targets. Use of this type of technology is partly responsible for the Navy's continuing successful performance in a demanding and hostile environment.

Aircrew mastery of this technology is significantly aided through use of computers. Besides freeing the aviator from tedious details in system operations, computers also provide significant decision analysis capability in target detection, identification and engagement procedures. Properly configured computers make it possible for the aviator to concentrate on flying the aircraft and to better manage the aircraft under various scenarios.

While computer technology is employed in aircraft systems as decision aids for aircrew, it is not used in aviation squadrons for maintenance managers. Presently there is no automated decision support aid available for those who manage

the maintenance on increasingly complex aircraft systems at the squadron level. The Naval Aviation Logistics Command Management Information System (NALCOMIS) represents an attempt by the Navy to establish a Management Information System (MIS) which captures all maintenance action. The system will undoubtedly improve maintenance managers' access to information; however, the manager must know a priori what information to seek and how to employ it. A Decision Support System/Expert System (DSS/ES) will aid the manager in considering relevant information and courses of action for a particular problem.

At the enlisted level, the maintenance manager is the Maintenance Control Chief (MCC). The MCC is generally a no nonsense manager and leader, who has proven himself "under fire" in stress filled operational environments. These individuals become experts in their field after years of dedicated hands on experience. During this process they compile vast stores of heuristic maintenance knowledge, and acquire their own proven individual knowledge bases.

Inexperience is often the cause of needless mistakes which result in an aircraft launching late or not taking off at all. Costs are thus incurred in the form of lowered operating levels. Computer assisted judgement can reduce wasted

materials, effort and time and result in better decisions. Today's squadrons, faced with constrained resources, cannot afford to perform at less than peak efficiency.

The demanding tempo of sea-going squadrons normally requires around-the-clock maintenance. This poses a serious problem--finding enough qualified experts, MCCs, to direct the maintenance effort 24 hours per day. The problem is further exasperated for shore based squadrons who schedule weekend maintenance by duty section. Additional complications for maintenance control occur when the MCC requires emergency leave, is transferred or retires.

McCaffrey [Ref. 1] proposed that the maintenance control environment is a suitable setting for implementing a DSS/ES to aid in the decision making process. Specifically, McCaffrey suggests the use of an ES to schedule the maintenance workload through prioritization of required jobs. A DSS/ES would allow the development of a decision making heuristic rule base for solving recurring problems in an environment plagued by high personnel turnover. Although its primary purpose is to help the less experienced manager, a DSS/ES designed to take advantage of a knowledge base interface may also help a seasoned manager maintain focus in a stressful, high pressure setting.

B. OBJECTIVE AND RESEARCH QUESTIONS

The objective of this study is:

Specification of the design criteria for a DSS/ES in the maintenance control environment.

The primary research question in this study is:

What are appropriate design criteria for a DSS/ES in the aviation maintenance control environment?

Subsidiary research questions for the DSS/ES are:

1. How should the system be implemented?
2. What method should be used to evaluate the system?
3. How will the system evolve?

C. METHODOLOGY

McCaffrey discussed the feasibility of using an ES system in the maintenance control environment. This thesis continues by analyzing the DSS/ES design methodology necessary for successful maintenance control implementation through study of current literature. Conclusions and recommendations about the techniques which will best ensure the success and acceptance of a DSS/ES in maintenance control are made.

This thesis is written under the following assumptions:

1. The work place of maintenance managers, maintenance control, will be outfitted with computer hardware. (This will be the result of NALCOMIS implementation.)

2. Future maintenance managers will be knowledgeable of basic computer commands and operations.

3. Although technology will change with time, maintenance managers will still confront the same types of problems in making decisions about the most efficient and effective use of resources.

D. ORGANIZATION OF STUDY

Chapter II is a discussion of the more popular ideas and theories on decision making, DSS/ES design, implementation, evaluation and evolution of such systems. Chapter III describes problems faced in the maintenance control environment. Chapter IV shows how DSS/ES design theory can be applied to maintenance control. Chapter V summarizes the conclusions and recommendations. The Appendix is a glossary of acronyms used within the study.

II. DSS/ES THEORY, STRUCTURE, DESIGN, EVALUATION AND EVOLUTION

This chapter examines a broad spectrum of literature on prominent thoughts for construction and implementation of a DSS/ES. Its purpose is to identify methodologies and techniques which will aid in designing a DSS/ES for use in aviation maintenance control. First is a discussion of the human decision making process and its importance to system design. Second, DSS/ES theory is analyzed relative to the need for and proper application of such systems. Next, the design process is examined with focus on Representations, Operations, Memory Aids and Control Mechanisms (ROMC) [Ref. 2] and adaptive design methods. The chapter concludes with suggested methods for successful DSS/ES implementation, evaluation and evolution.

A. DECISION MAKING THEORY

It is important to analyze the process humans use to make decisions. By doing so we are better prepared to design systems which emulate the process. It is also important to study the decision making environment of the organization.

Further, consideration must be given to an individual's cognitive style and how that affects his ability to assimilate and use data in the decision making process. These issues are examined below.

1. The Decision Making Process

The decision making process, according to Simon [Ref. 3], involves three phases: intelligence, design and choice. See Figure 2.1.

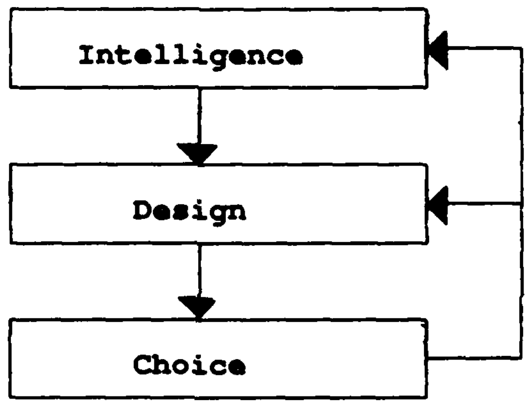


Figure 2.1 The Decision Making Process

Intelligence Phase--This is the phase in which problems are identified and classified. Raw data are obtained from the environment which form clues to identify problems in reaching the organization's goals or objectives. Once a problem is identified it is classified into a definable category by the decision maker. Categories could include, for example, programmed versus nonprogrammed problems. Programmed

problems are those where the solution is in the form of written guidance. The decision maker must conform to procedures. A nonprogrammed problem exists when the decision maker has complete freedom to make a decision without predefined guidance. The Intelligence Phase ends with a problem statement.

Design Phase--In the design phase alternative courses of action are conceived, designed and analyzed for feasibility. This involves understanding the problem, generating solutions and testing. Also, in this phase a model of the problem situation is constructed, tested and validated.

Choice Phase--This phase involves selecting a particular course of action from those available. A choice is made and implemented. It may be necessary to return to the intelligence or design phases if better problem definition is required or design flaws surface.

The design of a DSS/ES can be thought of as invoking this same process. The input and selection of various data for analysis might be referred to as the Intelligence Phase, the analysis of the data through use of various models, the Design Phase and selection of an optimal alternative or solution, the Choice Phase.

While other more detailed decision models exist, such as Soelberg's framework for analyzing the unprogrammed decision process [Ref. 4], Simon provides a simple, functional model for use in DSS design.

2. Cognitive Styles

Research in the area of cognitive style is aimed at trying to understand how the user thinks. How does he perceive, collect and analyze data? If users can be categorized according to their cognitive styles, then knowledge engineers can design friendlier, more effective systems.

"The feeling has been that if more is known about the various types of cognitive styles and if the users of a system can be correctly categorized it should be possible to design information systems that are more frequently used, resulting in greater decision-making effectiveness and are better accepted by users." [Ref. 5]

Mann cautions of investing too much effort in research devoted to measuring cognitive styles and that categorization of an individual's cognitive style is difficult. Individuals may also change their style over time or when presented with different data to analyze. This can present problems if cognitive style analysis is necessary.

Mann does not discount the value of further cognitive research but does surmise that present systems designed to offer the user a variety of dialog options can assist users who have varying cognitive styles. Huber also voices a similar opinion, "...the DSS design effort should be directed toward creating a DSS that is flexible, friendly and that provides a variety of options." [Ref. 6] In many applications, especially those with a variety of users, system functionality is more critical to success than tailoring the system to a particular user's style.

3. Organizational Decision Making

The decision process (intelligence, design and choice) may be common among all decision makers; however, the process can be greatly influenced by the environment or organization in which decisions have to be made. According to Huber, "...organizational environments have a great impact on managerial decision processes and choices." [Ref. 7]

Management science literature discusses various models of organizational decision making. Organizational decisions are decisions which do not relate to personal purposes, but to organizational purposes.

Huber analyzes some of the more popular organizational decision making models: the Rational Model, the

Political/Competitive Model, the Garbage Can Model and the Program Model. [Ref. 7]

The **Rational Model** describes an environment where available information is used logically for decision making by organizational units on behalf of the organization. This model is often used by organizations in self description to portray a desired image rather than reality.

The **Political/Competitive Model** describes a decision making environment where organizational units use information in decision making that they see will prove favorable to themselves. It can easily be confused with the Rational Model by decision makers as they attempt to justify political decisions as rational because they benefit a department and therefore the company.

The **Garbage Can Model** portrays an environment where solutions may precede problem identification; problems may be waiting for identification and ensuing solution, and in either case an opportunity exists for the decision maker if he takes action. A well known example of the problem being preceded by the solution is the 3M Company's Post-it Pads. In this case the solution, a nonpermanent adhesive, came before identification of the problem, a desire to attach temporary notes to office paperwork.

The **Program Model** emphasizes the effect of programs and programming on organizational decision making. This model is relevant to the military with its strong dependence on Standard Operating Procedures (SOP). Certainly any decision making system which involves the military will likely find its database heavily laden with written rules and regulations.

Huber's central point is that organizational decision environments vary greatly and have considerable impact on the decision making behavior of individuals. For this reason DSS/ES dialog design considerations should give strong consideration to the user's decision making environment as opposed to focusing on the individual user's cognitive style. [Ref. 6]

4. Non-Computer Aided Decision Support

Any decision support system should lend structure to the decision making process. All decision makers acquire or inherit a set of decision making tools to aid with the process. Huber has made a distinction between a computer aided decision support system as a "DSS" and a noncomputer aided decision support system such as file cabinets, index cards and reports, etc., as a "dss".

> Very, very few of the world's managers have access to a Decision Support System (a DSS, as defined by the books, articles and marketing materials that use this term). On the other hand, every manager has a "decision support

system," (a dss, a system consisting of the information sources and decision aids that the manager draws upon as the occasion requires). [Ref. 7]

To build an effective DSS a design engineer must have a complete understanding of the user's present dss. This insight will help him discern the information tools decision makers rely on. These tools will probably be present in some form in the new DSS.

B. DSS/ES STRUCTURE AND USE

Articles have been written with the sole purpose of distinguishing between a DSS and an ES. They both use computer hardware and software to assist decision makers, but each has unique characteristics.

The following describes the *reasons for recent* interest in the development of such systems as well as giving attention to the definition problem. Additionally, a framework used to guide knowledge engineers in identifying appropriate DSS/ES problem characteristics and in comparison of DSS and ES are provided.

1. DSS Theory

Computer systems which aid decision makers are becoming more powerful and popular with improved technology

and user awareness. Reasons for the current interest in DSS are attributable to:

1. Improvements in hardware, e.g., sophistication of input/output devices, increased speed, portability, reduced costs and increased availability.

2. Development of user friendly programming languages to facilitate system developments.

3. Users are becoming more sophisticated and knowledgeable on the benefits and use of computers.

4. A DSS fits in with the general trend in information systems development, e.g., office automation, professional workstations, distributed computing, computer graphics and advanced integrated systems (text, voice, graphics, data). [Ref. 8]

But what is a DSS? How does it differ from other information systems such as Electronic Data Processing (EDP)? Are the boundaries between different systems clear? The following paragraphs deal with each of these problems.

a. *Systems Definitions*

According to Sprague, "Decision Support Systems are a natural evolutionary advancement of information technology." [Ref. 9] He argues that there are clear and definite distinguishing characteristics between EDP, MIS and DSS. However, Sprague does point out that there are differences of opinion about the various definitions. Some claim that MIS is an all encompassing term for information technology as a whole in which DSS is just a part.

Most DSS definitions describe systems with similar characteristics. Sprague and Carlson define DSS as, "...computer based systems that help decision makers confront ill-structured problems through direct interaction with data and analysis models." [Ref. 2]

Recognizing the boundaries which separate various systems facilitates their identification. Mason [Ref. 10] contends that in the design of an information system the "point of articulation" or separation between the system and the decision maker will define the system. He uses five processes to characterize a system: Source, Data, Predictions and Inferences, Values and Choice, and Action.

The **Source** defines the physical activities and objects relevant to the business. **Data** refers to its observation, measurement and recording from the source. **Inferences and Predictions** are made from the data. The evaluation of inferences with regard to the values (objectives or goals) of the organization and choosing a course of action define the **Values and Choice** segment. The final process is taking a course of **Action**.

If the "point of articulation" lies between the **Data** and **Predictions and Inferences** segments, inputs to the

system are in the form of "Requests" and outputs are delivered as "Reports". Mason defines this type of system as a **database**. See Figure 2.2.

If the separation is between **Predictions and Inferences** and **Values and Choice**, with inputs as "What if" questions, and outputs given as "If--then," then the system is very similar to what we think of as a **DSS**. See Figure 2.3.

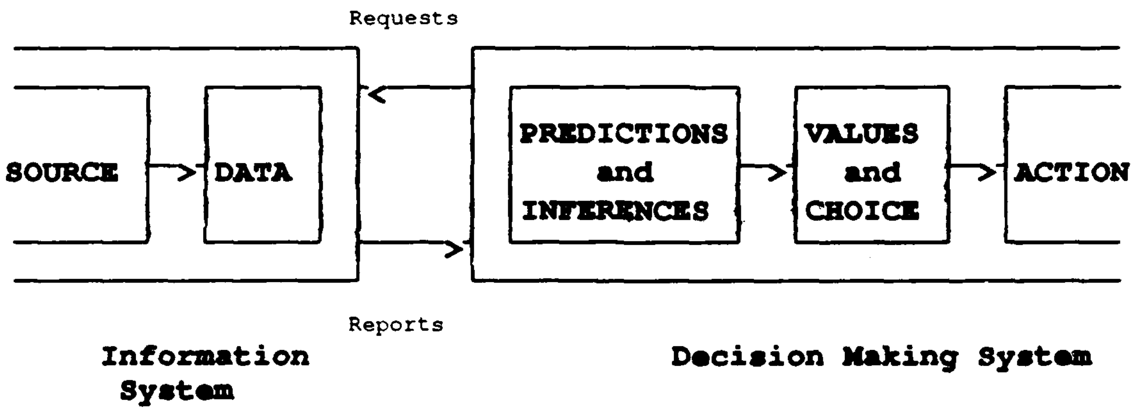


Figure 2.2 Database System

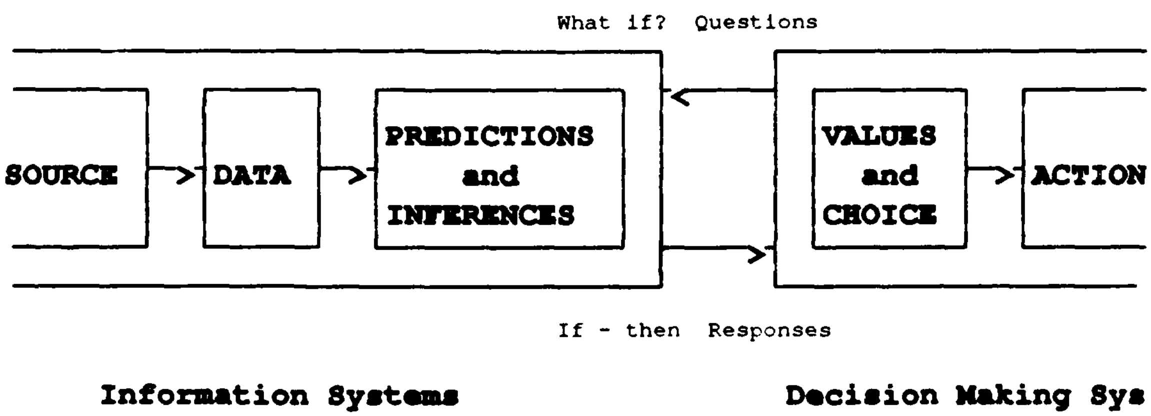


Figure 2.3 DSS

Between the last two segments **Values and Choice**, and **Action**, the inputs are "Which course of action is best?" and the output is a "Recommendation." This describes a system most would identify as an ES. See Figure 2.4.

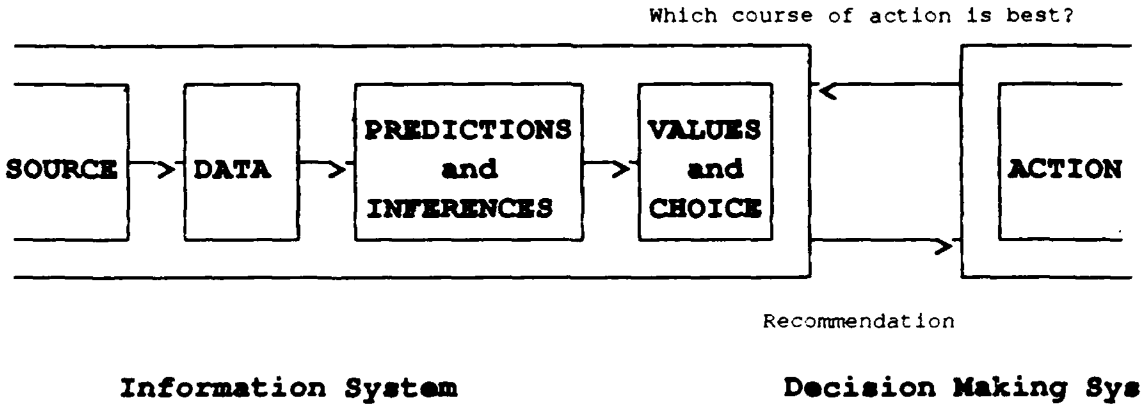
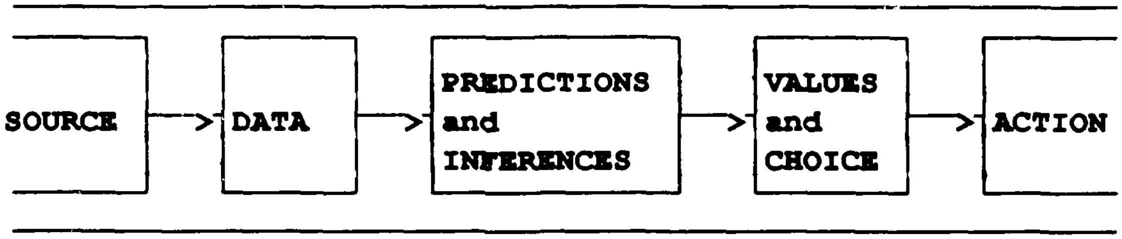


Figure 2.4 ES

Finally, if the information and decision making elements are combined into the same system we would have a **Decision Taking System**. This type of system equates to systems such as the air conditioning thermostat in homes. It senses the environment or collects data, makes an inference and a choice and takes action. In this case either turning the furnace on or off. At no point does the user of the system make this decision. See Figure 2.5.



Information (and Decision Making) System

Figure 2.5 Decision Taking System

b. A Framework

An organization which attempts to implement a computerized information system needs to determine specifically which type of decision makers it is meant to support. Managers who are involved in the daily routine of production will have specific and current data needs quite different than the CEO who wishes assistance in the area of long range strategic planning. For these reasons a guiding framework is needed for knowledge engineers to design more efficient systems targeted for the users they were developed to serve.

Gorry and Scott Morton [Ref. 11] have combined the thoughts of Simon [Ref. 3] and Anthony [Ref. 12] into a framework from which knowledge engineers can more efficiently target systems for specific decision arenas within the organization.

Simon classifies decision making problems as either structured, semi-structured or unstructured. A structured problem is one in which all three phases - intelligence, design and choice - are structured. Here, decision rules are used routinely for recurring problems. A spreadsheet would be an example of a solution for a recurring and structured type of problem. Semi-structured problems have one or two decision making phases unstructured. Unstructured problems have no structure in any phase.

Anthony has categorized three main managerial levels or activities. He defines them as Operational Control, Management Control and Strategic Planning. **Operational Control** concerns day-to-day production, ensuring that specific tasks are carried out effectively and efficiently. Here, data needs to be timely, accurate and detailed. **Management Control** is an activity which calls for decisions regarding the effective and efficient use of resources necessary for attaining an organization's goals. Informational needs are a mixture of those required for operational control and strategic planning. For example, budget preparation requires that consideration be given to plans for a new product based on monetary assets available for acquisistion. Information is often acquired through interpersonal interaction.

Strategic Planning is the process in which management sets an organization's goals and objectives. Strategic Planning problems are complex, usually nonrecurring and solutions are often framed from a historical perspective.

From these ideas the framework was developed as shown in Figure 2.6. The representative actions or problems in the framework are ones Gorry and Scott Morton believe typify the respective management activities. Problems below the horizontal dashed line are candidates for DSS aid. MIS and transaction processing systems are used for activities above the line.

DSS are designed for aiding semi-structured and unstructured problems. Gorry and Scott Morton suggest that by developing such a framework for organizations, knowledge engineers and managers can identify the types of problems for which a DSS may prove beneficial.

c. *Components of a DSS*

Computer based DSS are built around three main subsystems. These subsystems are the Data Subsystem, the Model Subsystem and the Dialog Subsystem (Dialog-Data-Model) referred to as the DDM paradigm. [Ref. 2] See Figure 2.7.

	Operational Control	Management Control	Strategic Planning
Structured	Accounts Receivable	Budget Analysis-Engineered Costs	Tanker Fleet Mix
	Order Entry	Short Term Forecasting	Warehouse and Factory Location
	Inventory Control		
Semi-Structured	Production Scheduling	Variance Analysis--Overall Budget	Mergers
	Cash Management	Budget Preparation	New Product Planning
Unstructured	PERT/COST Systems	Sales and Production	R&D Planning

Figure 2.6 Information Systems: A Framework

The **Dialog Subsystem** is that portion of the system through which the user interacts with the entire system. Bui [Ref. 13] claims that from the point of view of the users, "The DSS **is** the interface." He also states that although a well designed user interface does not guarantee the success of a DSS, "...its judicious design will definitely encourage the acceptance, boost the usage and enhance the analytical effectiveness of the DSS."

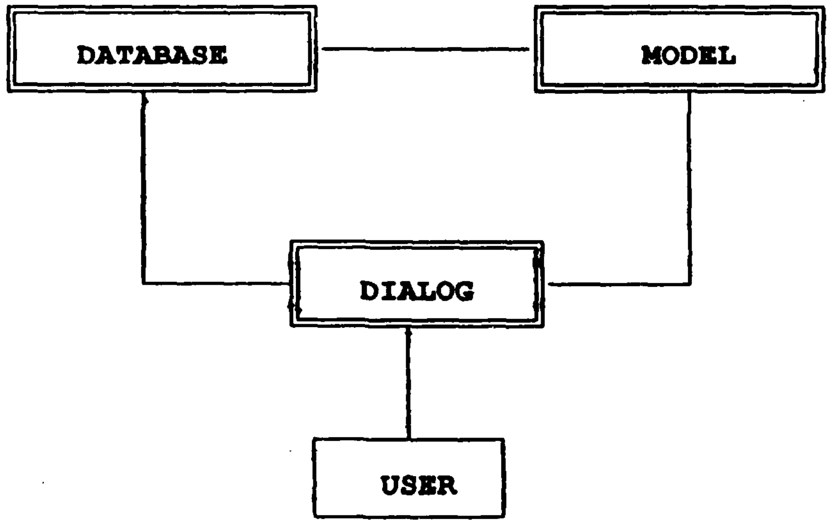


Figure 2.7 Components of a DSS

The **Data Subsystem** performs all data-related tasks, i.e., it maintains, stores and retrieves data. Data retrieval may be internal or even external to the system such that the system's database is tied to other databases. Data manipulation is controlled through use of a database management system (DBMS).

The **Model Subsystem** is the third major component of a DSS. It analyzes the data in the database through "analytic procedures and algorithms." A model may be as simple as one which computes the interest on a specified dollar amount, or extremely complicated such as a linear programming model with many variables. The importance of this subsystem is stated by Sprague and Carlson, "It is the integration of models into the information system that moves

an MIS which is based on integrated reporting and data base/data communication approaches into a full decision support system." [Ref. 2]

2. Expert Systems

Expert systems are designed to draw conclusions and make decisions, in a narrow problem domain, just as an actual human expert would. In fact, where the DSS is a system which is built to assist the decision maker, an ES, theoretically, may supplant the need for the full time presence of a human expert.

a. *Definition/Characteristics of ES*

Turban defines an ES as, "...a decision making and/or problem solving package of computer hardware and software that can reach a level of performance comparable to or even exceeding that of a human expert in some specialized and usually narrow problem area." [Ref. 14]

Turban cites the following as some of the more general and commonly accepted characteristics of a typical ES:

1. Capture and preserve perishable expertise from one or several experts.

2. Apply this expertise to solve, by using inferencing capabilities, complex problems effectively and efficiently.

3. Solve problems by providing answers instead of data.

4. Provide an explanation of how solutions are derived. [Ref. 14]

b. Structure of an ES

A modified framework of Turban and Watkins [Ref. 15] used to describe the structure of a ES is shown in Figure 2.8.

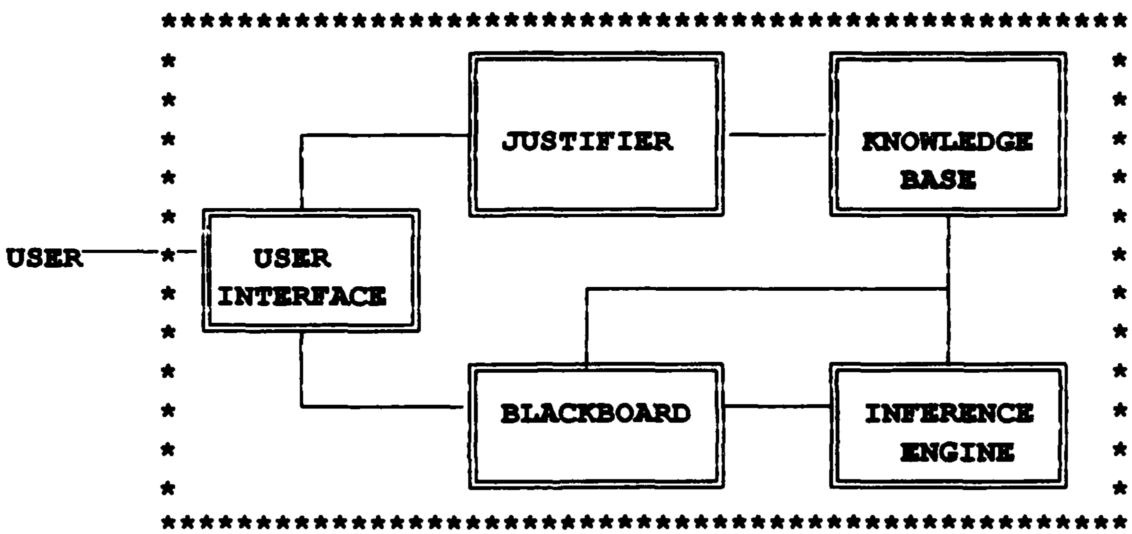


Figure 2.8 ES Structure

The Knowledge Base is to the ES what a database is to a DSS. However, the Knowledge Base of an ES is unique in that it contains knowledge as well as facts. Facts are usually raw data and definitions. Knowledge is usually the heuristic summation of the expert. Most Knowledge Bases store heuristic information in "Modus Ponens" form --if/then rules. Methods of acquiring knowledge or heuristics from experts is difficult and is the subject of an entire field of study. In

fact, knowledge acquisition is often referred to as the "bottleneck" in ES development. [Ref. 16]

The **Inference Engine** is the brain of the ES. It is basically a computer program which uses various methods for searching through the rule base to derive a conclusion. Common operations employed for conducting searches through the rule base are either forward or backward chaining using either a depth or breadth type of scan.

The **Blackboard** or work place, is the working memory. Here facts are entered and stored which pertain to the specific problem at hand. The Blackboard also records and displays for the user if desired, the intermediate results of the system on its way to a final conclusion.

The **User Interface** is that portion of the system which relates to the Dialog component of a DDM paradigm. It is through the user interface that the machine and user exchange queries and responses to solve problems. A natural language interface may be used.

The **Justifier** allows the user to see why the computer formed the conclusion it did. It allows the user to determine "how" a conclusion was reached and "why" a particular alternative was rejected.

3. Comparison of DSS/ES

Both a DSS and an ES are designed to aid users in a decision making environment. There are many similarities and differences between the two systems.

> The objective of a DSS is to support the user in the decision making process by providing access to data and models. The objective of an ES is to provide the user with a conclusion or decision significantly better, or more often correct, than the user could reach. A DSS allows the user to confront a problem in a flexible, personal way in manipulating the data and models. With an ES, the user has little or no flexibility. [Ref. 17]

Table 2.1 [Ref. 15] summarizes some of the more general differences between a DSS and an ES.

C. DESIGN METHODS

The design of decision support systems and expert systems has been described as more art than a science. Each field has evolved its own design methodologies. In addition, these techniques differ from established information systems design procedures. A combination of accepted DSS and ES design techniques may prove to be a prudent strategy for building a system and is examined in this thesis.

DSS/ES development is often difficult to justify in terms of dollars saved or return on investment. Alternatives to cost-benefit analysis are frequently required because of

TABLE 2.1 THE DIFFERENCES BETWEEN DSS AND ES

	DSS	ES
Objective	Assist human	Replicate expert and replace him
Who makes decision	The human	The system
Major orientation	Decision making	Xfer of expertise (human-mch-human)
Query direction	Human queries the machine	Machine queries the human
Clients	Individual and/or group users	Individual user
Manipulation	Numerical	Symbolic
Problem area	Complex, wide	Narrow domain
Database	Factual knowledge	Procedural and factual knowledge

unique characteristics of decision support and expert systems as compared with transaction processing systems. Also, because DSS/ES functions and outputs are not specific and easily defined as compared to systems such as transaction processing systems, its evolutionary life cycle tends to differ. In the following paragraphs these issues and others are addressed and options are proposed to contend with the atypical attributes of DSS/ES.

1. DSS/ES Design

The popular system life cycle model consists of five stages. These are design, construction, implementation, operation and maintenance. Slight variations exist but in general it is around this framework that traditional systems analysis and design methods are based. The systems life cycle approach has proven to be suitable for designing structured systems capable of performing repetitive tasks.

This is not the best method for designing a DSS. Most authors agree that, "The way of designing a DSS is different from that of a transaction processing system," [Ref. 18] and that, "DSS has peculiarities that make it unique among the rest of MIS." [Ref. 19] "A fundamental assumption in the traditional "life cycle" approach is that the requirements can be determined prior to the start of the design and development process." [Ref. 18] This assumption does not always hold true when building a DSS. Alternative methods; Representations, Operations, Memory aids and Control mechanisms (ROMC) and adaptive design, provide the design techniques more suited for a DSS.

a. *The ROMC Design Method*

Sprague and Carlson propose ROMC as a framework for defining the functional requirements and capabilities of a DSS.

> The approach is based on a set of four user-oriented entities: Representations, Operations, Memory Aids and Control Mechanisms. The capabilities of the DSS from the user's point of view derive from its ability to provide representations to help conceptualize and communicate the problem or decision situation, operations to analyze and manipulate those representations, memory aids to assist the user in linking the representations and operations and control mechanisms to handle and use the entire system. [Ref. 2]

Representations facilitate the user's portrayal of his problem and the objects associated with the problem. A Taxi Cab company in a large city would have a map of the city with the location of its taxis. This is used to help the dispatcher picture where the cabs are at any given moment. A computer screen can show this in much the same way allowing the user to visualize the situation. For example, the display on the screen could show green dots representing empty cabs and red dots representing cabs with fares. See Figure 2.9 #1 for more examples.

The Operations portion of the ROMC technique relies heavily on Simon's intelligence, design and choice scheme. The system must have the capability to gather and

manipulate data from various sources to give the user meaningful output. See Figure 2.9 #2.

Memory aids afford the user a convenient means to record intermediate data inputs as well as long term information. For example, a catering service receives orders and must keep a record of a customer's requests for an event. The person taking the order writes it down on a receipt or a note pad. A computer scratchpad does the same job. Given proper backup habits, it can not get lost or misplaced as easily as the order forms. It also provides an easy means to check customer data for details such as payment habits. See Figure 2.9 #3.

The Control Mechanisms give the user the power to manipulate the representations. Included are help commands, menus and access to command languages for experienced users desiring more power. Control Mechanisms may be the most important of the four in the long run. "The control aids may be crucial to the success of the DSS because they help the decision maker direct the use of the DSS and because they must help the decision maker acquire the new styles, skill and knowledge needed to make effective use of the DSS." [Ref. 2]

DECISION MAKERS' USE	DSS PROVIDES
1. Conceptualizations	1. Representations
• A city map	• A map outline
• Relationship between assets and liabilities	• A scatterplot of assets vs. liabilities
	• A graph of monthly asset/ liability ratios
2. Different Decision-Making Processes and Decision Types, All Involving Activities for Intelligence, Design, and Choice	2. Operations for Intelligence, Design, and Choice
• Gather data on customers	• Query the data base
• Create alternative customer assignments for sales personnel	• Update list to show assignments
• Compare alternatives	• Print summary statistics on each alternative
3. A Variety of Memory Aids	3. Automated Memory Aids
• List of customers	• Extracted data on customers
• Summary sheets on customers	• Views of customer data
• Table showing sales personnel and their customer assignments	• Workspace for developing assignment tables
• File drawer with old tables	• Library for saving tables
• Scratch paper	• Temporary storage
• Staff reminders	• DSS messages
4. A Variety of Styles, Skills, and Knowledge Applied Via Direct, Personal Control	4. Aids to Direct, Personal Control
• Accepted conventions for interpersonal communication	• Conventions for user-computer communication
• Orders to staff	• Training and explanation in how to give orders to the DSS
• Standard operating procedures	• Procedures formed from DSS operations
• Revise orders or procedures	• Override DSS defaults or procedures

Figure 2.9 ROMC Design Method [Ref. 2]

In other words the control mechanisms must be strong enough to help the new user in becoming comfortable. They must also be flexible and yield power to the experienced user. Users will demand more out of the DSS as they become familiar with its capabilities. See Figure 2.9 #4.

It should be noted that the ROMC method is not the actual design methodology. "The ROMC approach is a tool for focusing the systems analysis (of the decision-making system) preceding the design of the DSS and for structuring the actual DSS design." [Ref. 2] In effect, the ROMC approach "packages" the dss into a DSS.

b. Adaptive Design

ROMC enables the systems analyst to identify necessary attributes of a DSS. However, it is difficult to recognize all of the features the system should have from the onset of a project nor is the complete problem domain always recognized.

The adaptive design approach allows for the DSS to evolve as more becomes known about the problem area. It is well suited to DSS because as Hogue and Watson state, "... a DSS is never completely finished." [Ref. 20] One reason that a DSS is never finished is "...because the decision maker or user cannot define the functional

requirements of the DSS in advance." [Ref. 9] "Also, as an inherent part of the DSS design and implementation process, the user and designer will 'learn' about the decision task and environment, thereby identifying new and unanticipated functional requirements." [Ref. 18] By assuming an adaptive attitude designers and users readily accept necessary changes and improvements resulting in a more effective system.

Use of an adaptive strategy has not solved all complications encountered in building a DSS. When a system is nearing completion and it is discovered that a remaining essential function is either too difficult or expensive, the entire project may be jeopardized. The options at this juncture range from inconvenient to disastrous as decisions must be made regarding the future of the project.

c. *The Archipelagian Approach*

Bui and Sivasankaran propose a solution to this problem in the form of an Archipelagian Approach to DSS design. This approach makes extensive use of adaptive design techniques except in regions with high structure. In the structured domain the authors advocate less user involvement and lean toward traditional design methods.

The archipelagian approach is a means to identify and deal with obstacles before the project is started. "The

method works by (i) dividing complex ill-structured problems into 'islands' of both ill-structured and structured sub-problems, (ii) identifying and determining the adequacy of tools for their implementation, (iii) alerting the developer's attention to possible infeasible aspects of the system early and (iv) suggesting an implementation scheme that 'bridges' these islands in a manner that (the) development sequence best satisfies the user's priorities and system builder's requirements." [Ref. 21]

Accomplishability and Imperative Factors are assigned to the various models and then combined in a formula to reach a Development Priority Factor (DPF). The DPF is used to determine which modules should be built first. Use of this method will result in building the hardest and most critical parts of the system first. It will in turn ensure that a large outlay of funds does not lead to an infeasible, yet almost complete project.

d. System/Environment Definition

Before design begins it is important to distinguish a system's boundary to facilitate design engineers' ability to identify the inputs and outputs. Efraim Turban describes a system in terms of inputs, processes and

outputs as well as defining the clear separation between the system and its environment. Figure 2.10 [Ref. 14]

Turban's system characterization lends itself well to a manufacturing scenario where the raw materials are input into the system and processed through various activities to provide the desired output. The success of the output, measured by quantity, quality, performance, etc., is determined by the decision maker. This constitutes "searching the environment" for possible problems, (the first step in the decision making process, intelligence). This evaluation of the output calls for modification of elements within the input or the process.

There are also external fators which have an effect on decision making called environment elements. These include weather, customers, vendors and competition, elements existing outside the system's boundry. To be termed an environment element Turban claims two tests must be passed. First, the decision maker should be unable to manipulate the element. Second, the element must have an affect on system goals.

With the environment and the factors affecting system output identified the designer gains a clear and basic representation of the system he is trying to construct.

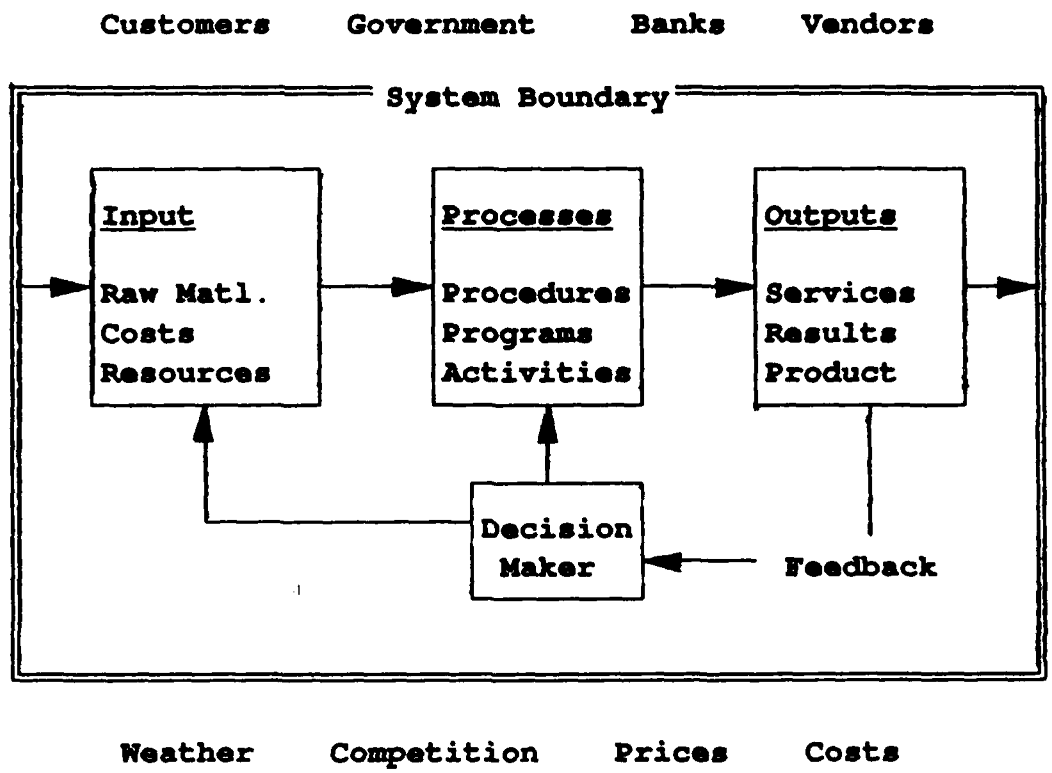


Figure 2.10 The System and Its Environment

e. Other Design Considerations

Other design considerations include incorporating existing hardware and software when possible and structuring the DSS/ES such that the user's abilities may range from computer novice to expert.

The database component provides the greatest opportunity to use existing assets. Having a database prior to building a DSS will reduce development expense and data redundancy and will simplify design. [Ref. 2] An impediment to using an existing database is compatibility with the

hardware and software selected to support the DSS/ES. This must be considered prior to making design decisions.

D. EVALUATION AND EVOLUTION

The need to discern certain design criteria ranging from an understanding of decision making factors to definition of the problem environment has been identified. ROMC and adaptive design have been proposed as construction methods, however, before any system can be built there must be some justification for the expense that will be incurred. This can be difficult when a complete description of the system's final capabilities is not known. Should a cost-benefit analysis, utilizing best guess information, or some other technique capable of accommodating the unknowns be used? What accommodations in design must be considered to facilitate system evolution demanded by changing technology and user requirements? The answer lies in the use of both value analysis and adaptive design.

1. Evaluation: Value Analysis

"Traditional cost-benefit analysis can be performed successfully for DSS that display a high degree of structure, aim at decisions that are made in a fairly certain environment and primarily address the intelligence phase." [Ref. 19] As

intangible benefits come into play cost-benefit analysis becomes more complex.

> The managers (users of DSS) perceive the main intangible benefits to be: facilitation of thoughts, improvement of communication and a sense of success and capability to perform sensitivity analysis. Evaluation of intangible benefits is subjective, sometimes impossible and as the weight of such benefits increases in the valuation process, so does the potential gap between the value and price of the system. [Ref. 19]

Many authors agree with Keen that:

> Traditional cost-benefit analysis is not well-suited to DSS. The decision to build a DSS seems to be based on value, rather than cost. The system represents an investment for future effectiveness. A useful analogue is management education. A company will sponsor a five day course on strategic planning, organizational development or management control systems on the basis of perceived need or long term value. There is no attempt to look at payback period or ROI, nor does management expect a direct improvement in earnings per share. [Ref. 22]

Keen also gives a representative list of commonly cited benefits of a DSS. This list, Table 2.2, shows that most of the items are difficult to measure.

Value Analysis as suggested by Keen is illustrated in Figure 2.11. In stage one the designer and user identify what they believe to be possible benefits of the system. Then, a cost threshold is determined based on what the user would be willing to pay to attain these benefits.

TABLE 2.2 DSS BENEFITS

1. **Increase in number of alternatives examined**
2. **Better understanding of the business**
3. **Fast response to unexpected situations**
4. **Ability to carry out ad hoc analysis**
5. **New insights and learning**
6. **Improved communication**
7. **Control**
8. **Cost savings**
9. **Better decisions**
10. **More effective teamwork**
11. **Time savings**
12. **Making better use of data source**

If a prototype can be constructed while staying within the bounds of the cost threshold, then the project continues. If not, the project ceases before any funds are committed. Arbitrarily choosing benefits may result in a system that does exactly what the user asked it to do. This may not be what the user needs the system to do. It is important that the benefits used in Value Analysis are closely aligned with the critical success factors (CSF) of the user and organization.

> Goals represent the end points that an organization hopes to reach. Critical success factors, however, are the areas in which good performance is necessary to ensure attainment of those goals. [Ref. 23]

Establish Value:

Define operational list of benefits:

e.g., solves urgent business problem,
provides a flexible tool for recurrent analysis,
makes planning data quickly accessible,
saves time in recurrent *ad hoc* reporting

Determine Cost Threshold:

Define maximum one would be ready to pay to gain the benefits
Determine if a prototype can be built that delivers the necessary capabilities

Build Version 0:

Define an architecture that permits the full system to be evolved from the initial Version 0.
Define routines for prototype

Stage I

Assess Prototype:

Review benefits; revise and extend list
Review desired and obtainable capabilities
Define functional capabilities of full system

Establish Cost of Version 1:

How much will the full system cost?

Determine Benefit Threshold:

What level of benefits must be obtained to justify the investment in the full system?
What is the likelihood these can be obtained?

Stage II

Build Version 1

Evolve Version N

Review usage, evaluate new capabilities desired or obtainable
Establish cost
Determine benefit threshold

Figure 2.11 Value Analysis [Ref. 22]

Assuming that the project is to proceed, the prototype, Version 0, is constructed and then evaluated using Table 2.2 and the prototype assessment model [Ref. 8] shown in Figure 2.12. This process continues indefinitely as the project evolves.

Value analysis works well with an adaptive design philosophy. It encourages prototyping and provides a convenient vehicle to monitor whether a system is measuring up to expectations, a continual evaluation process.

What remains to be seen is how the system will evolve. Do the techniques identified lend themselves to an orderly growth process? What is the evolution strategy best suited for DSS/ES?

2. Evolution

Adaptive design technique and value analysis by their nature dictate that the system will start small, usually with a prototype and continue to grow in size and capabilities as possible benefits are identified. The initial prototype will emerge in the form of a module designed to solve a specific problem. Adaptive design encourages development of future modules to satisfy user requirements as they are identified. Each proposed module should undergo the archipelagian process to determine feasibility.

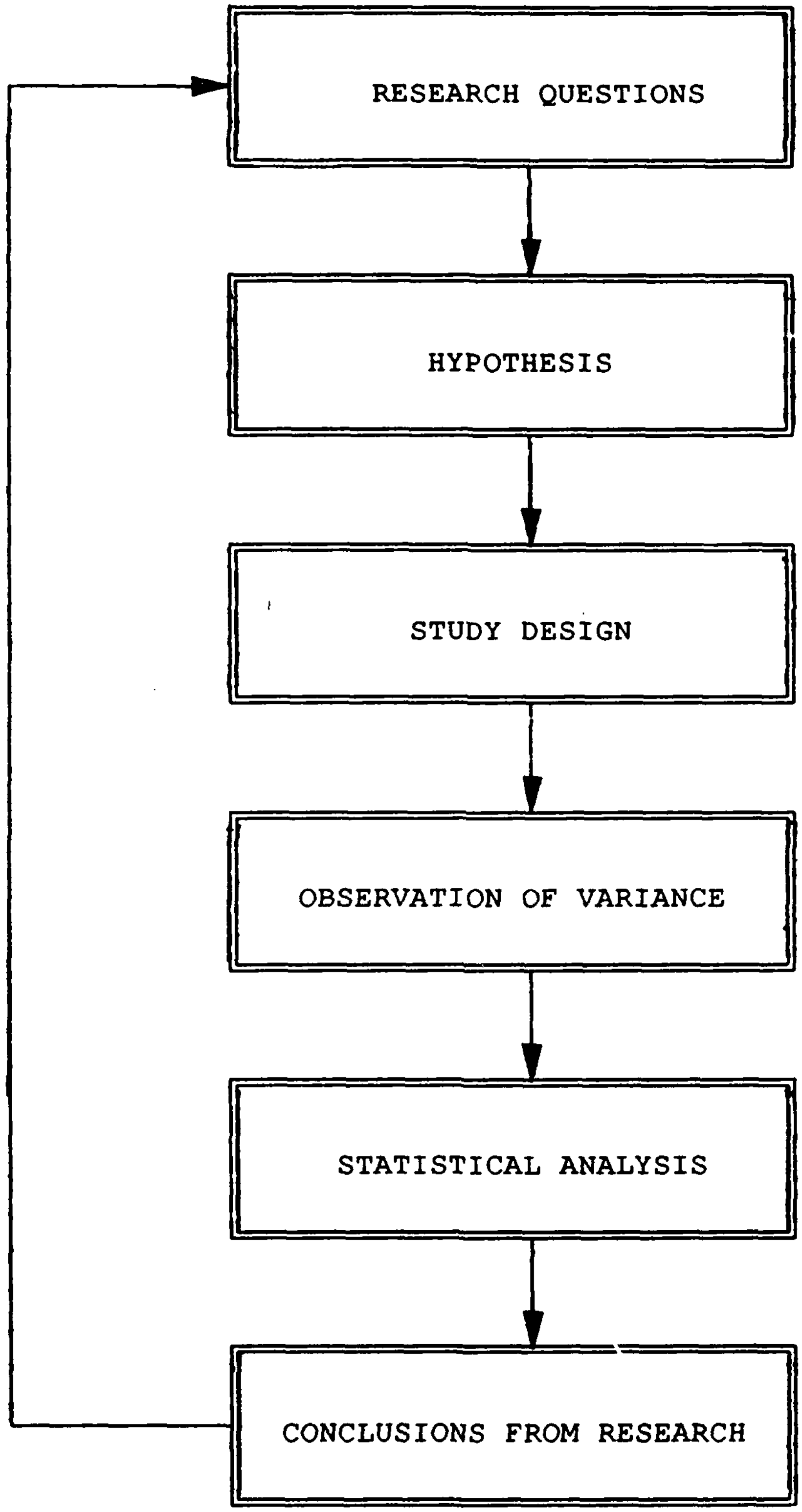


Figure 2.12 Prototype Assessment Model

The final system may only bare a slight resemblance to the prototype in appearance and functions. This is contrary to the maturing process in the traditional life cycle where a system ages and is maintained, but not significantly modified. There will be cases, particularly if the system is small in scope and easily defined, where the conventional life cycle approach can be utilized and established design procedures may be appropriate.

E. SUMMARY

Due to dramatic improvements in computer hardware and reduced costs, computers have become powerful personal tools. Now, managers are utilizing computers in decision makin These systems are referred to as Decision Support and Expert Systems.

These systems differ from previous information systems such as Electronic Data Processing which focus on transaction processing and Management Information Systems which rely on database systems for report generation. A DSS incorporates a model subsystem which manipulates data in the database often through mathematical algorithms. An ES uses inferencing techniques to reach conclusions about information stored as rules and facts in its knowledge base.

There are marked differences between a DSS and an ES as to structure, type of software and even appropriate environments. However, the essential difference lies in their purpose. A DSS is built strictly as an assistant to the decision maker. This is done primarily through ad hoc queries which explore various alternatives. An ES on the other hand, provides expertise in the absence of an expert. Where the DSS responds to user query, an ES may, when a need exists for additional data, query the user.

Maintenance control is a decision making work center which performs no better than the decision makers it employs. Developing and retaining "expert" decision makers is a continuing problem. The authors believe that the scarcity of "experts" in the maintenance control environment can be mitigated, throughout Naval Aviation, with DSS/ES implementation. This would be accomplished by the system's ability to improve the "nonexpert's" decision making performance.

Discussion thus far has focused on information about decision making, DSS/ES structure and design, justification, evaluation and evolution. Consideration of each issue is required prior to DSS/ES application in maintenance control.

A DSS/ES designer must understand the factors that affect decision making. He must be able to identify the ill structured problems of the decision making environment to which a DSS will lend support. After problem identification, data, models and heuristic knowledge bases required for decision assistance, can be determined and developed.

ROMC is recommended as a technique that will help the designer to identify essential features of a DSS/ES by adaption of the user's present dss. A high degree of flexibility is needed to accommodate systems with multiple users of varying cognitive styles. ROMC permits such flexibility in its use of representations and control mechanisms.

The design of a DSS/ES is better suited to an adaptive/prototype style of development vice the traditional "life cycle" approach. This is primarily due to the user's inability to identify requirements from the beginning. Prototyping and adaptive design allows for system modification and evolution due to changing user requirements and emerging technology.

Managers who propose the implementation of a DSS/ES in their organizations often have difficulty justifying such a system if a "cost-benefit" analysis is the means of

justification. This is because of the many intangible benefits in the analysis. Justification can be derived using value analysis techniques to identify and evaluate intangible benefits.

Chapter II has discussed general issues involved in DSS/ES design and implementation. Chapter IV will describe the form these issues take with practical application to maintenance control.

III. THE ENVIRONMENT: MAINTENANCE CONTROL

Good system design can only flow from a thorough understanding of the environment for which a DSS is being developed. A background summary of maintenance control's responsibilities followed by a scenario depicting typical problems provides a view of the environment. The objective is to identify the types of problems the Maintenance Control Chief (MCC) must deal with routinely. This will establish a reference base for the recommended design of a decision making system.

A. MAINTENANCE CONTROL: BACKGROUND

Modern aviation performs in a complex and unforgiving technological environment. Consequently, associated maintenance activities are virtually smothered in programs designed to ensure quality and safety. Solutions to problems which fall in the domain of such programs are usually inflexible and handled with specific procedures.

To acquire appreciation for the depth of knowledge required by an "expert" maintenance controller, Table 3.1 lists some of the major programs involved in "programmed" decision making as listed in the OPNAVINST 4790.2D. [Ref. 24]

TABLE 3.1 COMMON AVIATION MAINTENANCE PROGRAMS

Naval Aviation Maintenance
Personnel Qualification Standards
Certification/Licensing
Training
Analytical Maintenance
3-M Reporting
Fuel Surveillance
Oil Analysis
Aviators Breathing Oxygen Surveillance/Contamination
Hydraulic Contamination Control
Surveillance of Nitrogen Servicing/Equipment
Foreign Object Damage
Tool Control
Corrosion Prevention/Control Program
Tire-Wheel Maintenance and Safety
Aircraft Receipt and Transfer
Configuration Management
Weight and Balance
Special Interest Aircraft
Cannibalization
Preservation, Shipment and Storage
Hearing Conservation
Ordnance Handling
Support Equipment
Issue Priority System
Pack-Up Kits
Flight Packets
Aircraft Log Books
Aircraft Inventory Record
Aeronautical Equipment Service Records
Aircraft Inventory Reporting System
Aircraft Engine Accounting System
Compass Calibration
Aircraft Armament Equipment Pool

Many of the subject areas listed require a detailed working knowledge. Such knowledge is the sum result of many years

association with naval aviation maintenance. From the discussion in Chapter II, Simon would consider such problems to be structured or "programmed."

Maintenance control is the focal point for managing the maintenance of material assets to meet mission requirements. As such it is the maintenance department's single most important work center. In brief, its mission is accomplished through: (1) directing all scheduled and unscheduled maintenance of squadron aircraft (A/C); (2) assigning the daily maintenance work load; and (3) establishing work priorities. Scheduled maintenance alone involves a complex myriad of activities. The MCC must constantly juggle decisions involving aircraft assignments to fill a flight schedule. He must not only consider mission necessities but also periodic requirements for special inspections and maintenance required by higher directives such as the OPNAVINST 4790 series. (Complete responsibilities for each maintenance billet and work center are delineated in Chief of Naval Operations Instruction, OPNAVINST 4790.2D.) [Ref. 24]

The maintenance department's organizational chart for a Navy squadron is shown in Figure 3.1. The Maintenance Officer is usually an 04 to 05 who has overall department head responsibility. His right hand man is the Maintenance

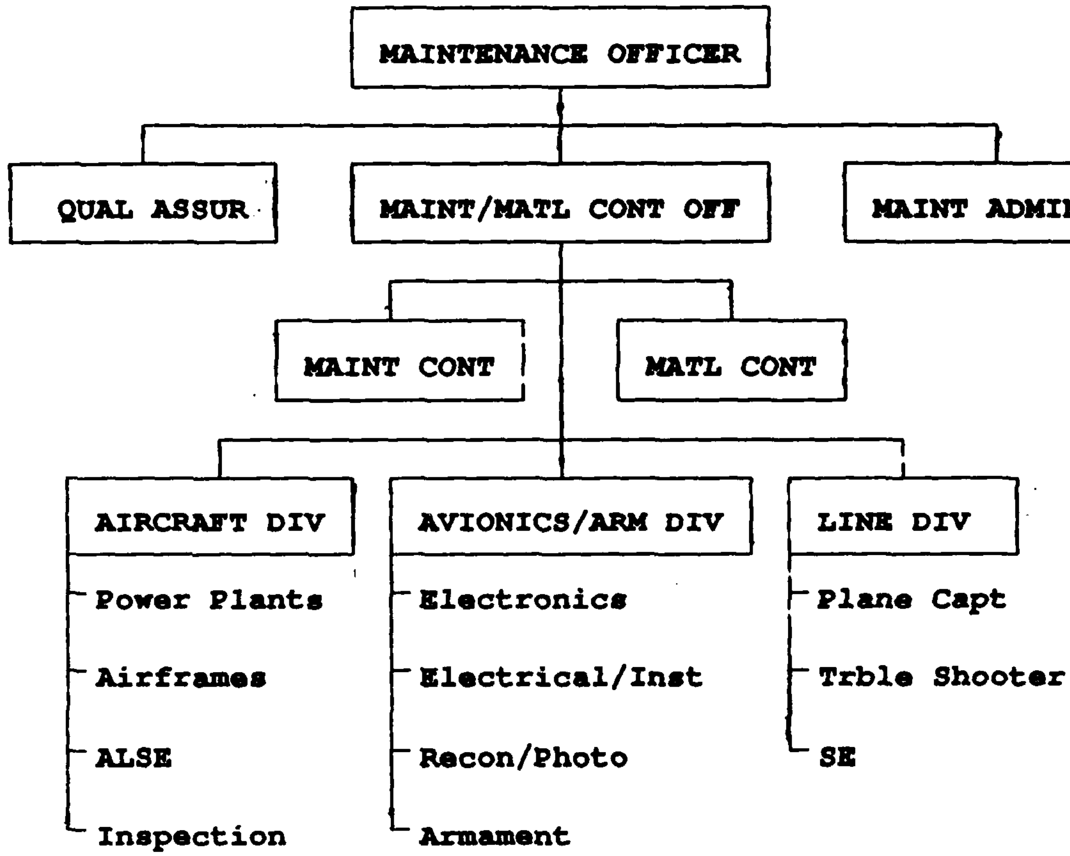


Figure 3.1 - Squadron Maintenance Department

Material Control Officer (MMCO) who is responsible for both the maintenance and material control work centers. At the enlisted level, Maintenance Control is managed by the "Maintenance Control Chief" (MCC). The MCC is typically an E7-E9 who has substantial experience in the maintenance sphere and a reputation for being an accomplished facilitator. It is at this level in the maintenance department, where the vast majority of daily production decisions are made, that our DSS/ES is primarily targeted.

B. MAINTENANCE CONTROL SCENARIO

The following scenario is used to help describe the problem environment and is only one example of the many complex issues facing maintenance control personnel. It gives a representative example of what actually takes place and of the decision making in maintenance control.

It was 1400 Friday afternoon. Senior Chief Foster was filling out the passdown log for the weekend duty section. Senior Chief Foster was proud to be the "Maintenance Chief" of VP-21. He now ran the show even though he knew his boss, MMCO LT DuPuy, would forget this fact from time to time.

The Senior Chief was filling the shoes of retired Master Chief Jack Synder who had retired last Wednesday. Synder had been a dynamic force in the maintenance department with over thirty years aviation maintenance experience. When the Master Chief spoke--everybody listened. Synder had been recognized as among the elite in the west coast P-3 community. He had often been tasked by the Air Wing to move in temporarily at other squadrons and help "straighten things out." Under Master Chief Synder's tutelage VP-21 had won the Golden Wrench Award the last two years and was credited with having the best corrosion prevention program in the fleet. He was the best, but after 33 years he had hung it up.

Master Chief Synder had hand picked Senior Chief Foster as his replacement. The Senior Chief was a true professional. He was competent, tireless, dedicated, and devoutly loyal. He brought with him 22 years of maintenance experience with 6 of those having been served in maintenance control. Synder had been impressed with the Senior Chief's ability to work well "under fire" and to anticipate future problems. The Master Chief had also been impressed with Foster's ability to handle both "assertive" officers and "reluctant" aircrew.

This Friday afternoon the Senior Chief was primarily concerned with Monday's flight schedule. VP-21 had been chosen to assist with a CNO project analyzing underwater acoustical sensitivity under varying ocean conditions such as salinity, temperature, and depth. Much of the project was classified. All the Senior Chief knew was that both the Maintenance Officer LCDR Fastrack and the MMCO LT DuPuy made it very clear that on Monday a fully mission capable (FMC) aircraft would be available for the flight with another aircraft, also FMC, standing by. This was a high visibility event which required the assistance of two VIP's. One VIP was from the CNO's Research & Development staff and the other was a professor from the acoustical laboratory at the Naval Postgraduate School.

The Senior Chief was reviewing the status of his air force as shown by the Visual Information Display (VID) boards on the wall. These are pocket filled boards which display maintenance discrepancies documented against each aircraft by work center. He entered the following notes in the passdown log for AD1 Taylor. Taylor was on the Maintenance Control Watch Bill for the weekend duty section. See Table 3.2 for passdown.

Petty Officer Taylor was the Power Plants Supervisor. An excellent jet engine mechanic, he had stood the Maintenance Control Watch several times before, but this was the first time flights were scheduled while he stood the watch. The squadron was behind on its training flights and wanted badly to get a Saturday flight out. The Senior Chief knew Taylor was a good man who had handled Maintenance Control well before. However, he had planned to drop in Saturday afternoon just to see how things were going. He did not want to show up first thing in the morning as he knew Taylor would sense a lack of confidence.

TABLE 3.2 PASSDOWN LOG

A/C	Status	Passdown
RD1	FMC	Will fly Monday on "Special Projects" flight.
RD2	PMCM	Still flying. Work off return gripes as you can.
RD3	PHASE D	Phase inspection to be finished this PM. Perform daily inspection and prepare for check flight. Bird will turn around after check flight for Nav. hop.
RD4	FMC	Use as backup for "Special Projects" flight Monday.
RD5	PMCS	Have electricians continue to work on autopilot.
RD6	PHASE B	Pull into hangar to begin PHASE B Monday.
RD7	SDLM	A/C still at SDLM (Standard Depot Level Maintenance) undergoing rework.

RD1 had been the squadron workhorse. Time after time she had come through and performed well during important missions. For this reason the Senior Chief had chosen her for the special projects flight Monday. However, RD1 had a high-time generator on the number two engine. They were already well into the ten percent rule. (This is a rule which allows maintenance managers to go beyond the maximum replacement hours by ten percent for some components.) Twelve hours remained before the aircraft would have to be grounded or downed for maintenance. RD4 was presently FMC and had done

well her last two times out. Therefore, RD4 was selected as the backup.

Saturday morning AD1 Taylor was in at 0630 preparing for the 0730 maintenance meeting. He reviewed Senior's passdown notes and noted the flight schedule for the day which listed two flights both scheduled for RD3. The flight schedule listed a one hour check flight for a 0900 takeoff. The navigation flight was a turnaround event scheduled for six hours with a 1015 launch. Taylor knew he would be at the squadron all day.

At 0730 the duty section mustered in maintenance control for the meeting. Petty Officer Taylor briefed the duty section on the flights for the day and basically let the shops work on what they felt was required. He told the electricians, known as AE's, that the Senior Chief wanted them to work on RD5's autopilot. Just before the meeting broke up Airman Dalton, a member of the phase crew, told Taylor that on buttoning up RD3 yesterday evening they were missing a screwdriver. They thought they knew where it was and had planned on looking for it first thing this morning. They would have notified Maintenance Control yesterday but they knew they would have to hang around until they found it and

they had to come in today anyway. They didn't know the plan was to fly the aircraft today.

There was a maintenance instruction which covered missing tools. Taylor had read it long ago. As a supervisor he was well aware of the procedure--call Maintenance Control, Maintenance Control downs the airplane until the tool is either found or the inspection team headed by the Quality Assurance (QA) Department determines the tool is not on board the aircraft. He notified the duty section QA representative, AMS2 Phillips. He told Phillips, "Hurry up and get an inspection team together and find that tool. The pilots will be in any time now to start their preflight." He thought he had better review the instruction. Where was it? Maintenance Control keeps a copy of all such instructions...somewhere.

A half hour later LCDR Dave Hustle and LT Ross, the pilot and copilot, started reviewing the Aircraft Discrepancy Book (ADB) to become familiar with discrepancies written from the last ten flights. This was standard procedure and a requirement of OPNAVINST 4790. It was obvious Mr. Hustle was not happy about having to come in on a Saturday. He complained about many of the maintenance sign offs. The pilots signed the A Card, accepting the aircraft, and started their preflight.

AMS2 Phillips entered maintenance control and said they had completed a thorough inspection of RD3 and had not found the missing screwdriver. He thought he had better call his boss Senior Chief Davies. Phillips returned shortly saying Mrs. Davies claimed the Senior Chief was out and would have him call as soon as he returned. Taylor pressed Phillips for a determination reminding him that the aircraft was technically down with a crew in preflight. After a strong reminder from Taylor to Phillips that Phillips was in charge at the moment, not Senior Chief Davies, Phillips said the aircraft was up as far as he was concerned. He did not think the tool had been left on the aircraft. At 1005 RD3 had "wheels in the well."

At 1015 Senior Chief Davies called maintenance control. After AD1 Taylor briefed him, Davies began to rant and rave about proper procedures. He shouted that only the Maintenance Officer could "up" an aircraft if the tool was not found. (Actually the instruction called for a decision by the MO or the acting MO, the next in command). He further stated that if the MO could not be contacted, the aircraft would have to be recalled immediately.

Taylor then called Senior Chief Foster rather than LT Depuy, who was the acting MO. Mrs. Foster said that he was

running errands and planned to stop by the squadron before returning home. Petty Officer Taylor decided to recall RD3.

Twenty minutes later RD3 was on deck. After issuing a verbal lashing, LCDR Hustle demanded to know which aircraft they were now going to assign on the navigation hop. He was not going to wait around all day for RD3 and wanted another aircraft. AD1 Taylor assigned him RD5. Seeing the aircraft had an autopilot gripe, Hustle exploded. He was not going to "bore holes in the sky for five to six hours without an autopilot." He knew RD1 was a good plane and he demanded it. RD1 was airborne fifty minutes later.

At 1400 Senior Chief Foster entered maintenance control. After Taylor's brief, Foster took time to regain his composure and think about the situation. RD1 was now out of the picture for Monday. There would not be enough hours left to conduct the mission due to the generator drop dead time. That meant RD4 would have to be the primary. RD3 still needed a check flight and that meant one of the remaining PMC birds would have to come up to FMC status by Monday per MO orders.

AE2 Johnson then walked into the work center. He wanted to know if he, Walker, and Smith, the remainder of the AE duty section, could secure for the day. He explained that neither he nor the others knew anything about the autopilot and had

basically just wasted the entire day trying to fix it. He further explained that RD2 was partial mission capable (PMC) for his shop only, had they worked on it they probably could have brought its status up to FMC.

At 1500 the MO, LCDR Fastrack, received the brief from LT DePuy. Fastrack declared Sunday a full work day until the squadron was caught up and ready for Monday. Senior Chief Foster was told that he, LT DePuy, and LCDR Fastrack were to brief the skipper Sunday at 0730 sharp as to why maintenance was "so screwed up."

Fortunately what is described is not the norm but it is a realistic example of occurrences that do arise from time to time. With the aid of a DSS/ES Petty Officer Taylor could have accessed the procedures to properly handle the missing tool. The missing tool was a programmed situation with little leeway for decision making. However, when the instruction could not be found, Petty Officer Taylor and Senior Chief Davies began making erroneous decisions. As noted the missing tool instruction specified that the acting MO will make the decision on whether to recall or not.

Taylor is not to be faulted for erring on the side of safety for recalling RD3. However, while the aircraft should have never been launched, a thorough QA inspection had been

conducted as required. The MO (or the acting MO) should have been afforded the chance to decide if a recall was necessary since the critical part of the procedure had been handled properly.

Petty Officer Taylor made another poor decision in assigning RD1 to LCDR Hustle. Under stress, Taylor was slightly overwhelmed and failed to notice the limited hours remaining on RD1. An ES incorporating aircraft scheduling would have flagged RD1 as a "high time" aircraft. This would have provided the argument needed to convince LCDR Hustle that the training flight should be cancelled to save RD1 for its operational commitment on Monday.

Similarly, if Senior Chief Foster had had the benefit of a DSS/ES the previous evening, he would not have insisted the AE's work on RD5's autopilot. He did a poor job of JCN prioritization. A database showing the qualifications of duty section personnel would have revealed this deficiency.

As this scenario demonstrates, a few mistakes and wrong decisions can easily bring a squadron's smooth operation to a grinding halt. It is highly unlikely that the individuals concerned will make the same mistakes again. However, these persons will most likely only be in the squadron for two more years on average.

Just as a wealth of knowledge and skill departed with Master Chief Synder, it will depart again when these sailors are transferred. A DSS/ES designed to capture and retain their expertise will go far in preventing others from learning the same lessons the hard way.

IV. DSS/ES DESIGN FOR NAVAL AVIATION MAINTENANCE CONTROL

The initial DSS/ES design must have a set of guiding standards for construction and development. These specifications should establish the "need for", the "ingredients of" and the "how to" of system design. Chapter IV addresses the primary thesis research question regarding definition of design criteria for a DSS/ES in maintenance control. The subsidiary research questions concerning system design, justification and how the system is to evolve are also answered.

A. DESIGN CRITERIA

The following criteria have been identified as applicable for the development of a DSS/ES, for any environment. Some may not apply in all cases, but most are general enough in nature to permit broad application. The criteria are:

1. Identify the need for a DSS/ES.
2. Identify the decision making factors.
3. Identify the present dss.
4. Identify the ill-structured problems.
5. Identify the problem related data.
6. Identify the required problem solving models.
7. Identify the required heuristic rule bases.

Each of these standards applicability with regard to maintenance control is discussed in the following paragraphs.

1. Need for a DSS

Not all problem environments require or would even benefit from a computerized decision support system. Problems which are easily solved through a common sense approach or through rote memorization of procedure, will not require the power of computer assistance. If systems were installed in these environments, they most likely would not be used.

This is not the case for the maintenance control domain. Maintenance control appears to be a fertile area for the application of DSS/ES. The decision making environment satisfies Simon's DSS requirement for complexity in that the user, the MCC, is confronted with problems lacking in structure. The lack of structure is caused in maintenance control by the shortage of experienced decision makers (experts), operational pressure and the stresses induced by time limitations. (Studies have shown that decision makers under stress often perform less efficiently. Stress decreases their ability to process information.) [Ref. 25]

Maintenance control is a problem environment in which decision makers are confronted with ill-structured problems

and can realize benefits through the employment of a computerized decision support system.

2. Decision Making Factors

Inputs/outputs, resources, user cognitive style and organizational decision making pressures are all factors which affect decision making. The recognition of these factors and the varying roles they play in making decisions will greatly assist the engineer in system design.

a. *Inputs and Outputs*

All decision processes are spurred through some form of stimuli (input), with the intention of achieving some goal (output). To design a decision support system which will assist the decision maker, the inputs and outputs must be identified.

Figure 4.1 shows the basic inputs which feed into maintenance control are "maintenance discrepancies" initiated either by the maintainers themselves or the aircrew, and the "flight schedule" which represents mission tasking. The processes involved include assigning and prioritizing the JCN's among the various work centers. The two outputs of maintenance control are repaired aircraft and aircraft assignments.

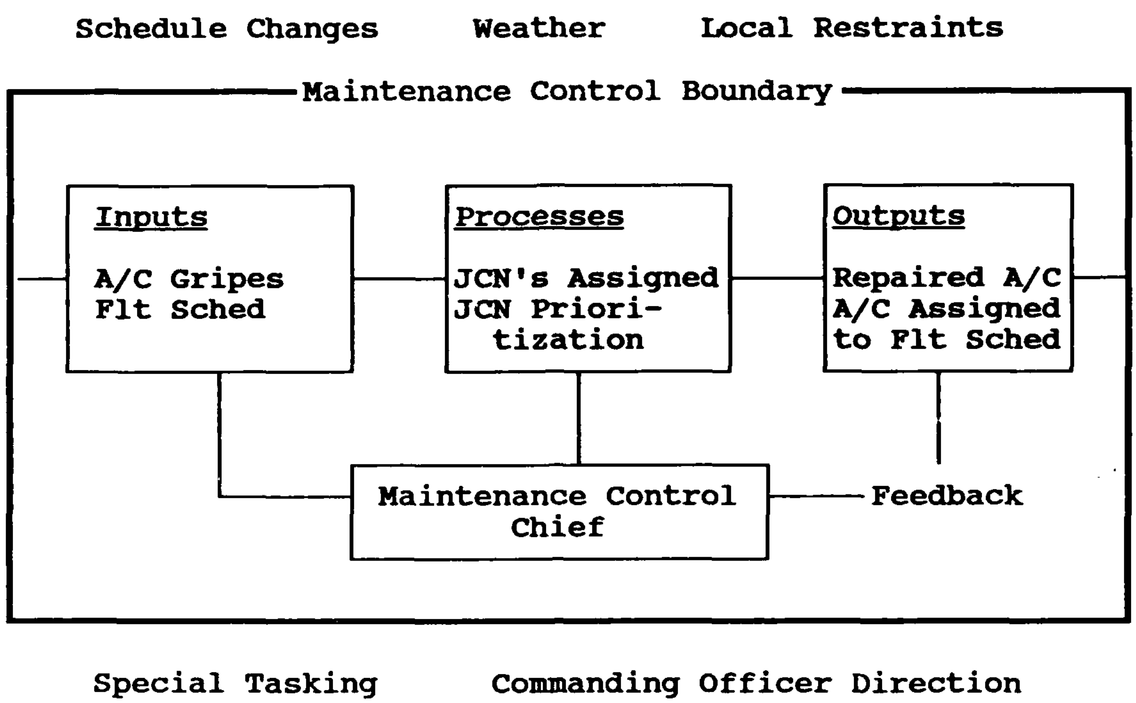


Figure 4.1 The Maintenance Control "System" and Environment

Environmental factors, as previously defined by Turban, are elements over which the MCC has little control, yet which affect his inputs and outputs. Such elements would include; (1) special direction by his superiors which might dictate aircraft assignment or repair priorities; (2) special tasking due to requirements for technical directive incorporation which may have to be complied with immediately; (3) schedule changes of the flight schedule or of upcoming deployments; (4) local restraints such as a Naval Air

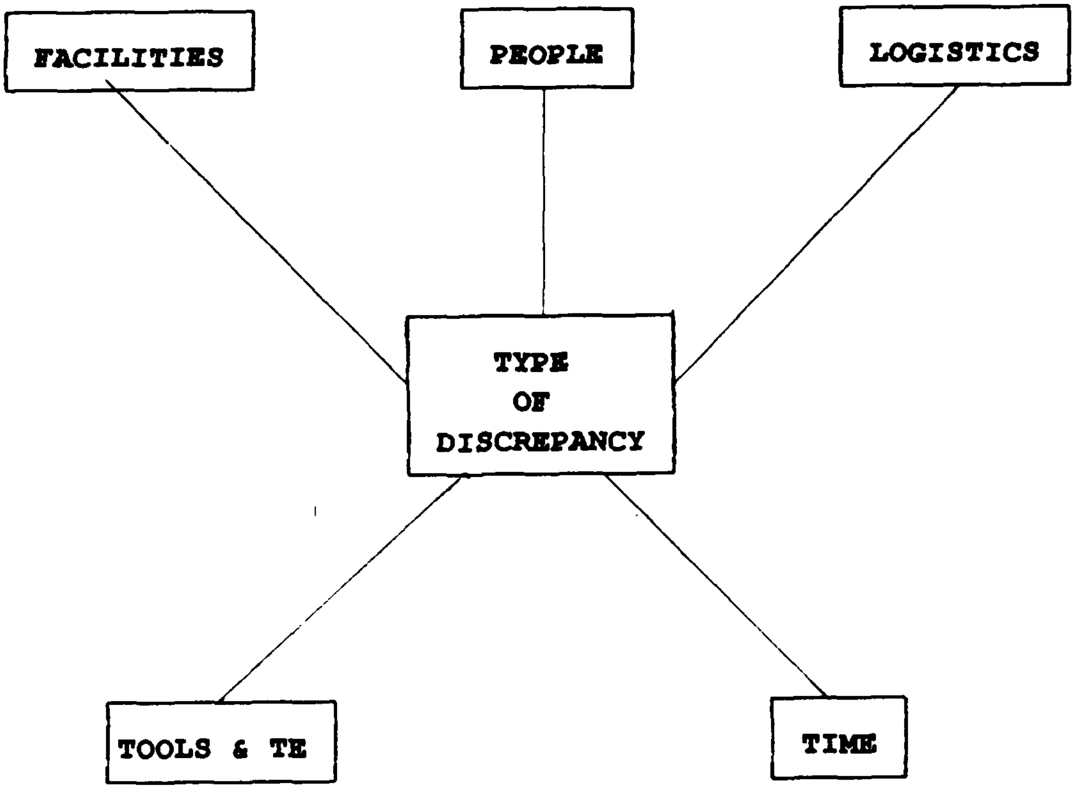
deployments; (4) local restraints such as a Naval Air Station's policy which might prohibit high power engine checks for maintenance purposes after certain hours of the day; and (5) the weather which might force some maintenance actions to be performed in an aircraft hangar.

This system view provides a perspective from which to define the inputs and goals of maintenance control and the external factors which affect them.

b. Resources

The engineer must identify the resources the decision maker has at his disposal for solving problems. If maintenance control's main goal or output is repaired aircraft, what resources are involved in the repair?

The authors have identified five resource groups about which the MCC must be constantly appraised if changes occur. If resource availability changes, this will affect repair capability and subsequently affect work priorities. These resources, or objects, may be represented in semantic net fashion, as discussed by Harmon and King. [Ref 15] See Figure 4.2.



FACILITIES	PEOPLE	LOGISTICS	TOOLS & TE	TIME
Light	Supervisor	Rep Parts	Available	Qty
Elec. Pwr	Quals	Consumables	Calibrated	
Pnu. Pwr	Duty Sec	Fuel/Oil/Nit		
Hyd. Pwr	Leave			
Space	Liberty			
Heat				
Roof				
SE				

Figure 4.2 - Maintenance Performance Ingredients Of The Problem Environment

Semantic nets consist of objects, attributes, and values. As shown, our main object, the aircraft discrepancy, will call to mind the possible use of five major resources or attributes. Each attribute has assorted possible values. For instance, requirement for hangar facilities may trigger a quick review of its values, e.g. the need for various forms of power, lighting, ample space, heat, etc.

The efficient and effective management of these five attributes is more of an art than a science. It is an art primarily developed through experience. The MCC expert develops his own heuristic set of rules from which to judge and implement courses of action and decisions.

c. *Cognitive Style*

The system engineer should evaluate the importance of cognitive style to his system. Each decision maker requires information upon which to base decisions and may vary in his determination as to what information should be sought and how it should be formatted. Therefore, slight variations in cognitive styles are to be expected among the many maintenance controllers performing throughout Naval Aviation.

This variety can only be accommodated through a design with maximum flexibility. A DSS/ES in maintenance control should afford the user multiple options for data

retrieval and display. Full use of menus, default options, color, sound and even mouse control accessories should be considered.

d. *Organizational Decision Making*

The design engineer may consider the affect of organizational pressures on decision making of far more concern than user cognitive style. This is true in maintenance control where many of the decisions are the result of SOP application. Because there are variations in some SOPs from one command to another a successful system will have to be flexible enough to work in various command climates.

A decision support system for maintenance control will require all decision related instructions pertaining to the targeted DSS/ES problems to be stored as database text files.

3. Present "dss"

In computerized system design it is necessary to identify all of the present decision making tools used by the decision maker. These tools are considered the MCC's dss as defined by Huber [Ref. 7]. In all Naval Aviation Maintenance Control work centers, MCC's inherit a dss, typically involving the items shown in Figure 4.3.

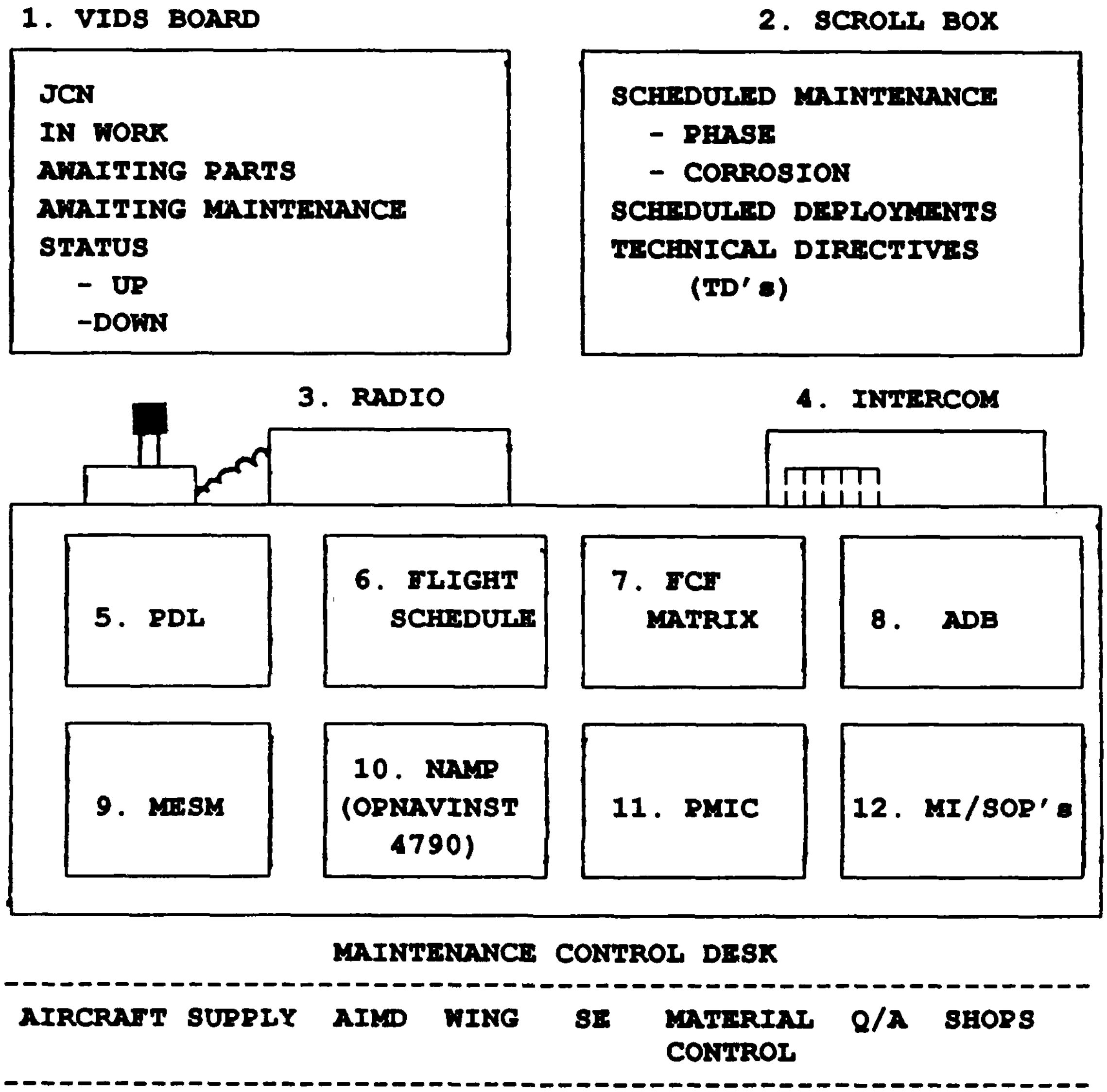
Item 1, the Visual Indication Display (VID) Board is used to display and organize the maintenance actions, or gripes, associated with a particular aircraft. The gripes are organized by a Job Control Number (JCN) and assigned to the required shop. Each gripe will be in one of three states; in work, awaiting maintenance, or awaiting parts. Gripes of such serious nature as to prevent flight are marked in red.

Item 2, the scroll box, is used to lay out scheduled commitments and best guess plans for performing future scheduled maintenance. Such things as phase inspections, incorporation of required technical directives and periodic corrosion work are scheduled on the box in calendar format by aircraft.

Item 3, the radio, is obviously used as a real time device for information collection directly from the repair personnel at the aircraft concerning the present status of a repair action.

Item 4, the intercom, is used for direct communication between maintenance control and all squadron maintenance shops including quality assurance and material control.

Item 5, the Pass Down Log, is the usual night check/day check feedback on the success of the shift and direction for the oncoming shift on particular gripes.



1. VISUAL INFORMATION DISPLAY BOARD
2. SCROLL BOX (MAINTENANCE PLANNING CHART)
3. RADIO FOR COMMUNICATION WITH AIRCRAFT
4. INTERCOM FOR COMMS WITH SHOPS, QA, MATERIAL CONTROL
5. PASS DOWN LOG (PDL) - INFO FROM THE PREVIOUS SHIFT
6. FLIGHT SCHEDULE
7. FUNCTIONAL CHECK FLIGHT (FCF) MATRIX - FCF REQMNTS
8. AIRCRAFT DISCREPANCY BOOK (ADB)
9. MISSION ESSENTIAL SYSTEM MATRIX (MESM)
10. NAVAL AVIATION MAINTENANCE PUBLICATION (NAMP)
11. PERIODIC MAINTENANCE INSPECTION CARDS (PMIC)
12. MAINTENANCE INSTRUCTIONS (MI) AND STANDARD OPERATING PROCEDURES (SOP)

Figure 4.3 - Present dss

Item 6, Flight Schedule, tells maintenance control what its operational tasking is for the day. The Maintenance Chief must ensure that his assets, squadron aircraft, are assigned in the most efficient manner possible to meet the flight schedule requirements.

Item 7, Functional Check Flight Matrix, provides information as to which completed maintenance actions will require a aircraft maintenance check flight by a qualified check pilot before it can be scheduled for normal operation.

Item 8, Aircraft Discrepancy Book, provides a historical record of maintenance actions on a particular aircraft.

Item 9, Mission Essential System Matrix, lists the systems required on a particular aircraft type to perform a specific mission.

Item 10, Naval Aviation Maintenance Program (OPNAVINST-4790 series), is referred to as the maintenance "Bible". It is a 5 volume publication which spells out specific do's and don't's for the entire field of Naval Aviation Maintenance.

Item 11, Periodic Maintenance Information Cards, list all aircraft components which are under specific inspection and removal plans for aircraft types.

Item 12, Maintenance Instructions and Standard Operating Procedures, is an attempt by squadrons to summarize other required directives into a condensed readable form for quick reference, as well as detailing specific guidance by the Commanding Officer.

4. Problem Identification

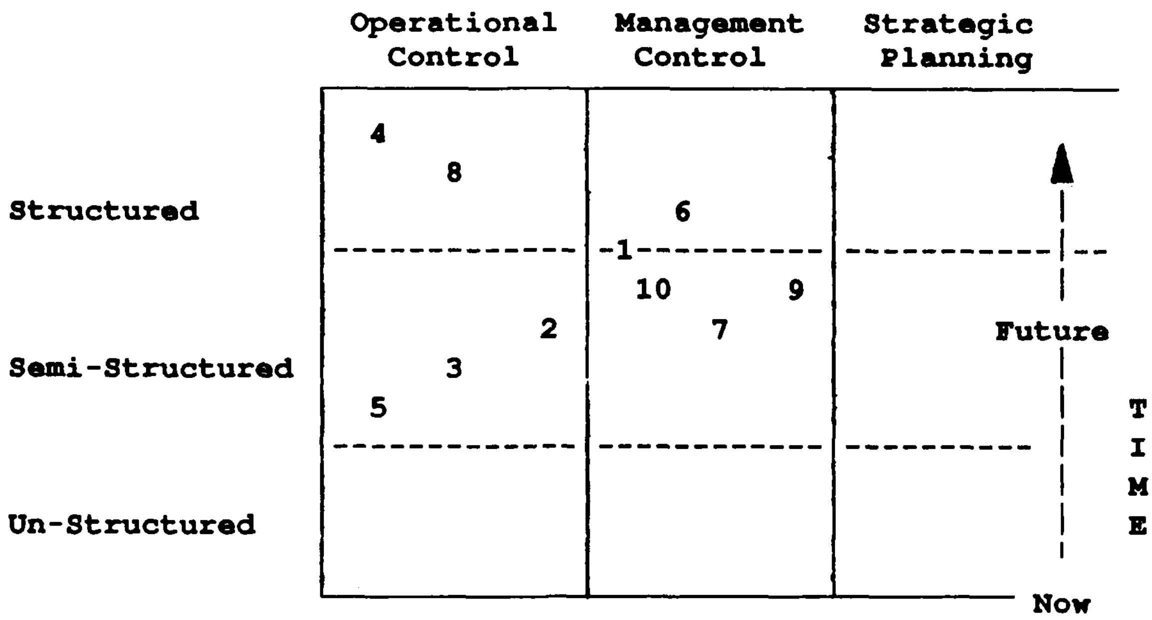
DSS/ES are designed to aid decision makers with semi-structured problems. Therefore, before design begins, system engineers and users must identify the problems appropriate for a DSS/ES. After identification of the semi-structured problems, engineers and users select which problems will be targeted for DSS/ES solution.

Decision making in maintenance control may seem straightforward and routine, especially considering the abundance of written guidance. Using Huber's model of decision making, maintenance control fits in the "programmed model" definition. Here, decision making is preprogrammed by written or verbal guidance requiring little ingenuity or resourcefulness on the part of the decision maker. Much of the military decision environment fits into the Programmed Model mold. One reason this is a necessity is because of high personnel turnover rates.

However, the program model does not describe any organization in its entirety, including maintenance control. As the scenario in Chapter III has shown, even in an environment heavily influenced by "programmed" decision making, uncertainty abounds and costly decision errors are made. In fact, if some of the routine decision making processes that typically occur in maintenance control are examined and placed in Gorry and Scott-Morton's framework, many fall into the semi-structured realm as shown in Figure 4.4.

As shown, item number 4, JCN assignment, is a well structured task. A particular discrepancy will fall under the cognizance of a certain shop. For example a radar system discrepancy will be assigned to the avionics branch for repair, a structured operational decision.

Conversely, item number 5, assigning the daily workload in the form of prioritizing JCNs, requires more heuristics and decisions begin to fall in the semi-structured realm. Uncertainty arises from several factors. Which aircraft is being pushed to meet tomorrow's flight schedule? Which missions will require certain systems to be up and running? How does one system's discrepancy affect another system? Which personnel are on board with the required



1. Direct Scheduled Maint.
2. Direct Unscheduled Maint.
3. Aircraft Assignment
4. JCN Assignment
5. JCN Prioritization
6. Leave recommendation
7. Personnel Shift Assg
8. Where to park Acft
9. Shift Schedule
10. Cannibalize or not

Figure 4.4 Decision Framework

expertise in tonight's shift? It does little good to assign a particular discrepancy as a shop's highest priority if the people with the requisite skills are not available to perform the task.

Borrowing a part (cannibalization) from a known good system to replace a bad part in another aircraft is often a routine consideration for a Maintenance Chief. Yet certain constraints may make decisions which are typically routine

for the decision maker non-routine. They therefore become semi-structured or un-structured. For example, if supply does not have a replacement part for a faulty item and the part is necessary for certain mission performance, then cannibalization is normally justified. But, in a case where the cannibalizing of the part may result in damage to the part a judgement has to be made based upon the risk of damage. If the risk of damage is high, the result could be two down aircraft. In such a case a strong argument against cannibalization can be made.

As Figure 4.4 shows there are a significant number of decision areas in maintenance control that fall in the semi-structured range. Such problems will benefit from an effective DSS/ES.

5. Relevant Data Identification

Only after the particular problems have been targeted for solution will it become clear which data is needed for problem solution. Once the necessary data is identified the engineer has defined the necessary contents of his database. For instance, if support is sought for cannibalization decisions, all cannibalization actions and related instructions would be required data. The instructions will ensure that procedures are properly followed while access to

all cannibalization actions ensures that the MCC will consider cannibalization rates when he makes his decision. Another example is the problem of scheduled maintenance. Scheduled maintenance requirements are dictated by aircraft hours flown. Therefore, flight hours consumed per aircraft will have to be captured, summed and stored. For each problem there are similar pieces of data that must be identified.

6. Decision Making Models

It now remains for the design engineer to assist the human decision maker by developing decision making models. The criteria developed thus far would be necessary for the development of a MIS as well as a DSS/ES, but when algorithmic processes are introduced, information systems are transformed into decision support systems.

As an example, Figure 4.4 identified scheduled aircraft maintenance as a semi-structured problem for which a decision support system would provide user assistance. After the problem and required data have been identified it becomes a matter of what algorithmic procedure should be developed to provide the best solutions to problems.

The problem, scheduled maintenance, deals with completion of required aircraft and component inspections. Some requirements include removal or installation of new

systems or components and are usually based on consumption of flight hours, e.g., the aircraft with the high time generator in the Chapter III scenario. Most scheduled maintenance requirements contain a factor of flexibility such as the 10% rule which allowed the example aircraft to exceed the maximum flight hours permitted by 10% before generator removal. These requirements are published in such directives as the OPNAVINST 4790 for all naval aircraft, and the PMIC, discussed in Chapter II for an aircraft type.

Most guidance will be in the form of flight hours flown. However, in some cases requirements are based on calendar days or hours not flown, e.g., daily inspection requirements. (Of course any special guidance through Type or Wing Commanders would also have to be programmed.)

Scheduled maintenance becomes complicated when attempting to ensure the maximum material availability during predicted peak operating periods. Holidays, deployments, assignments of the "ready alert" status are all planning factors which must be considered.

A model involving scheduled maintenance will require the ability to perform arithmetic operations. These operations will include the tracking and summation of aircraft flight hours per aircraft. Such a model in a DSS would easily

permit maintenance managers the ability to access the phase inspection requirements for all aircraft during the next month based on predicted flight hours. With this information the managers may elect to complete some inspections early, anticipating heavy operations in the near future. Also, such information will allow material control supervisors to plan ahead by ordering extra "phase kits".

These decision making models must be capable of processing data relevant to maintenance control, the output must conform to organizational decision making constraints and results should reflect a satisfactory solution to the targeted problems.

7. ES Knowledge Base

Some semi-structured problems in Figure 4.4 do not lend themselves to mathematical solution, e.g., prioritizing JCNs. The order that aircraft discrepancies should be worked is a daily puzzle which if approached incorrectly will induce inefficient use of available resources. McCaffrey discussed the approach to this problem in the context of an expert system with a heuristic knowledge base incorporating the rules of thumb an expert uses in making decisions. These heuristic rules are searched through chaining and inferencing techniques to arrive at a solution. If AD1 Taylor had access to such a

knowledge base he would have prevented shop personnel from establishing their own priorities. Shop personnel are often unaware of the big picture and often direct their attention to "favorite gripes." If not guided by maintenance control, material availability can suffer.

The criteria specified in this section provide the design engineer with the raw materials necessary for system design. First he has established a need for the DSS/ES. Next, an understanding of decision making factors, the present dss and the problems allows him to conceptualize the environment. Finally, problem related data can be processed with applicable decision making models or heuristic rule bases to arrive at a solution. These raw materials are used with ROMC to begin actual system design.

B. DESIGN FRAMEWORK

ROMC provides a framework to delineate system capabilities. By showing the characteristics in the form of Representations, Operations, Memory Aids and Controls, the designer can grasp what the proposed system will look like. ROMC is also used to identify specifications for the Dialog, Data and Model (DDM) paradigm. To compile attributes for a system the designer must conduct extensive interviews and

observe the decision maker in his work environment. Actual observation is beyond the scope and time constraints of this thesis so representative examples have been provided from the authors' personal experiences. Figure 4.5 shows Sprague and Carlson's ROMC method as it is applied in the aviation maintenance control environment.

1. Representations

When the decision maker envisions a problem with aircraft he sees them as either UP or DOWN. A common practice in maintenance control is to have displays showing an aircraft as either green (UP) or red (DOWN). In applying the ROMC design method a computer screen should also be capable of presenting red and green aircraft figures on the screen.

It can be argued that providing the decision maker with pictures of airplanes does not make his job any easier as he already has this aid available. This example is used only to show that the DSS will continue to provide the user with the aids he is currently using.

There are other conceptualizations that exist only as mental images. For example, when the shops report estimated time to repair a discrepancy, the MCC forms an imaginary time line in his head. This is easy enough if there is only one job being performed on one aircraft. Unfortunately the norm

is that numerous jobs are being performed on multiple aircraft and these tasks are often interrelated. A representation on the computer screen in the form of a Gantt chart would help the decision maker retain the big picture avoiding confusion about when each job will be finished.

2. Operations

The DSS must also have certain operational features. Figure 4.5 shows a partial list of necessary capabilities such as a database query function to retrieve status of parts information and the ability to prioritize work on aircraft (JCN prioritization). An Expert System capacity can be used to select aircraft for assignment to a flight schedule based on heuristic rules of expected time required to fix a discrepancy or the likelihood that a part procured through cannibalization will correct a discrepancy. An ES shell can also be programmed for use as an on-screen checklist. This is particularly useful in providing guidance for the user about procedures from instructions for incidents such as lost tools or fuel spills.

ROMC operations help describe the model component of the DDM paradigm. A linear programming model will be applied to provide optimization capability necessary for planning long term scheduled maintenance, aircraft assignment to the flight

schedule and personnel shift assignments. A heuristic rule based model is applicable for directing unscheduled maintenance and JCN prioritization.

Another function of operations is to be able to query a database. Because much of the data needed for the models will be stored in the NALCOMIS database, the system must be built with NALCOMIS compatibility as a consideration.

3. Memory Aids

A decision maker in any given environment has certain tools to help keep track of necessary information used to arrive at a solution. It is no different in maintenance control. The MCC makes extensive use of tools such as a passdown log to keep track of tasking, a scheduled maintenance planning chart, and a multitude of instructions guiding him on proper procedures.

These tools or memory aids while critical for proper job performance are often hard to find, cumbersome to use and sometimes difficult to understand. A misplaced passdown log can be an inconvenience, and in some circumstances can bring the maintenance effort to a halt. As shown in Chapter III the inability to quickly find and refer to an instruction can result in chaos. A DSS constructed to provide easy access to memory aids will mitigate these problems.

Memory aids include components identified as relevant to the present dss and consisting of the passdown log, scroll box, FCF matrix, MESM and ADB. These items are held in various forms and used differently. For example, if a spreadsheet aids in the manipulation of scroll box data, this information will be held in a spreadsheet file. A note pad allows the user to record passdown log information and a library function gives access to various instructions, both will be maintained in text files. Other information such as outstanding discrepancies against aircraft will be held in database files.

Design of memory aids as pull-down screens will give the user easy access to virtually any reference he needs. The user can work on a task and bring in references as required without interrupting his work. Careful attention to providing effortless retrieval of information will do much to guarantee use of the system. Memory aids should be powerful and promote convenience of system use.

4. Control Mechanisms

On line help, default values and menu displays are particularly helpful in orienting new users to a system. These control mechanisms are important in that they make

DECISION MAKER'S USE	DSS PROVIDES
1. Conceptualizations	1. Representations
-UP/DOWN Airplanes	-Miniature Airplanes (red/green)
-Hangar Space	-Hangar Floor Plan w/utilities depiction
-Time	-Gantt chart showing time required to fix the aircraft
-People (qual/quan)	-Pie chart to show quals Figures to show quantity
-Parts (availability)	-Printout from Material Control
-Tools (availability)	-Printout from Tool-Room
-Flight Schedule	-Screen display of flight schedule
2. Different Decision-Making Processes and Decision Types	2. Operations for Intelligence, Design, and Choice.
-Gather data on Gripes, Personal Qualifications, Parts, Tools and Test Equipment, and Facilities	-Query the Data Base -Expert Advice -Prioritize Aircraft -Print summary statistics on each aircraft
-Compare Alternatives	
3. A Variety of Memory Aids	3. Automated Memory Aids
-Passdown Log	-Scratchpad for Passdown
-Scroll Box	-Spreadsheet for Scroll Box
-FCF Matrix -MESM	-Library for FCF and MESM
-ADB	-List for ADB data
4. A Variety of Styles, Skills and Knowledge Applied Direct Personal Control	4. Aids to Direct, Personal Control
-4790 -MI/SOP's -PMIC -TD's	-On line Help -On line access to manuals -Default values -Page back Capability -Menu Displays

Figure 4.5 ROMC Application

running the system as easy as possible thus avoiding discouragement of users who are not comfortable with computer operations.

Control is also provided by ensuring that the system is in compliance with applicable Maintenance Instructions (MI's), Standard Operating Procedures (SOP's), Technical Directives (TD's), Periodic Maintenance Inspection Cards (PMIC's) and instructions such as OPNAVINST 4790. Actions recommended by the system must conform with regulations which bind the decision maker. This requirement identifies a need for ongoing system support. Squadrons must have access to, or ensure training of, someone to incorporate publication updates into the system. The squadron's technical publication librarian could be trained for this duty.

Application of the ROMC approach gives some definition to what the system should look like. The examples cited are a sample of possible features and an illustration of how these attributes can be represented using ROMC. A more detailed list can be derived from close observation of the maintenance control environment.

C. SYSTEM IMPLEMENTATION AND EVOLUTION

1. Value Analysis

Value analysis has been identified by Keen as an alternative to cost-benefit analysis for justifying a DSS/ES. To use value analysis, desired benefits are identified and the value to the user of attaining these benefits, in terms of dollars, is assigned to determine the cost threshold for producing the first prototype. A representative sampling of benefits that can be applied to a maintenance control DSS/ES follow.

Mitigation of the shortage of experts and more effective decision making are the primary benefits which should result from implementation of a DSS/ES in maintenance control.

While there is no definite and easy measure of decision quality there are some indicators. Increased aircraft readiness rates should be one indication of better decisions. A decrease in the ratio of maintenance man hours to flight hours is another. Another example of a benefit was shown in the scenario, aircraft down time while awaiting maintenance (AWM) could have been reduced by matching maintenance talent to aircraft discrepancies.

A further possible benefit is higher morale attained through job satisfaction. Morale may be diminished by ineffective decisions. For example, poor job prioritization decisions will lead to a lower aircraft readiness posture and may result in longer work days and a longer work week. This scenario will most definitely affect morale if continued over a sustained period of time.

Stress reduction due to faster problem response, an increase in alternatives examined, employment as a training aid for maintenance control personnel and a better understanding of decision factors affecting maintenance control are some other benefits that may be realized through DSS/ES implementation. The designer and user must decide which of these benefits are to be prioritized and then place a value on attaining them. This will establish the maximum cost for prototype development.

2. Prototyping and Adaptive Design

The initial prototype should be simple to operate and valuable to the user in performing a routine decision task. The objective is early, effective implementation which establishes value thus gaining user acceptance. Prior to prototype construction, close archipelagean scrutiny, as

described in Chapter II, is advised to avoid costly development of an infeasible project.

An aircraft assignment DSS is suggested as the initial prototype. The prototype software should be compatible with the Z-248 computer which is currently available for procurement. An "off the shelf" software package capable of linear programming could be utilized.

The authors envision a prototype which will optimize aircraft assignments based on mission requirements, aircraft capability, and scheduled maintenance limitations. The MCC can experiment with "what if" questions to determine the optimum utilization of his assets based on mission requirements and scheduled maintenance.

Benefits for value analysis-cost threshold purposes include better decision making, increased readiness rates, and an increase in the number of alternatives examined. After testing, the prototype will be evaluated on how well it fulfilled these expectations.

During the testing process the MCC will probably make suggestions on other desirable functions for the system in addition to those already planned. These ideas should be subjected to value analysis and the archipelagean method. If deemed feasible, the project can proceed to the next version

and the process is repeated again, starting the adaptive design process.

This modular approach using value analysis and adaptive design can continue until no more capabilities are identified. Value analysis will guard against cost over runs and project infeasibility with the end result being a powerful DSS/ES for use in maintenance control.

V. CONCLUSIONS AND RECOMMENDATIONS

Naval aviation maintenance managers operate in a complex decision making environment where maintenance control is the focal point. The opportunity for improved performance by maintenance control decision makers is the primary justification for the development and implementation of a maintenance control DSS/ES.

A. CONCLUSIONS

This thesis has examined design, implementation, evaluation and evolution issues involved with the development of a maintenance control DSS/ES. A set of DSS/ES design criteria has been developed which provide the design engineer with information about the decision environment and proposed system. These criteria are used in the ROMC framework to provide a blueprint of system characteristics. Prototyping and an adaptive design methodology are recommended as the most suitable alternatives for system design and implementation. Because of the difficulty of conducting a cost-benefit analysis for DSS/ES, value analysis is the preferred justification technique. The final system characteristics may

defy advance definition, therefore value analysis and adaptive design are recommended as the procedures to be used as the system evolves. The following paragraphs provide more detail on each of these conclusions.

1. Design Criteria

A design engineer must have certain information about a proposed system prior to starting design. This information is referred to as the design criteria. In Chapter IV a detailed discussion of the design criteria, appropriate for a maintenance control DSS/ES, was completed. By using the following set of design criteria, the design engineer will ensure the availability of the information required to confidently proceed to the next phase in the development of a maintenance control DSS/ES. Applicable maintenance control issues and situations are included as examples.

1. Identify the need for a DSS/ES.
   Not all problem environments are well suited for a DSS/ES solution. Emphasis should be on those environments which contain ill-structured problems. Maintenance control is a complex decision making environment due to the existence of ill-structured problems, e.g., aircraft scheduling, scheduled and unscheduled maintenance and work load prioritization.

2. Identify the decision making factors.
   Decision making factors are those which prompt and direct the course of decisions made to meet end goals. Such factors include identification of inputs/outputs, available resources, cognitive style and decision making pressures exerted through organizational structure.

The inputs to maintenance control are aircraft discrepancies and the flight schedule. These inputs prompt maintenance decisions which result in repaired aircraft and aircraft assignments to the flight schedule, the outputs.

Resources available to the maintenance manager are categorized into five areas, facilities, people, logistics, tools and test equipment, and time.

Individual cognitive style is not an appropriate concern in the maintenance control environment due to the large number of users. Therefore, a user friendly system which incorporates flexibility by providing a variety of user options, e.g., menus, default options, color, etc., is important.

There is an organizational decision making pressure exerted in maintenance control. This pressure exists in the form of written SOP meant to direct the decision maker with most programs.

3. <u>Identify the present "dss"</u>.
Successful design of a computerized DSS must incorporate the noncomputerized decision tools of the user, a dss. This will promote system acceptance by providing the user with information in a familiar format. Typical maintenance control decision making tools include VIDs Boards, SOP, ADBs, etc.

4. <u>Identify the ill-structured problems</u>.
Since ill-structured problems are of concern to DSS/ES designers, they need to be identified and targeted for solution. In maintenance control such problems include JCN prioritization and aircraft scheduling.

5. <u>Identify problem related data</u>.
Once problems have been identified, the required data necessary for their solution can be captured and stored for retrieval and manipulation. For example, most of the scheduled maintenance requirements are dictated by aircraft hours flown. Therefore, flight hours consumed per aircraft will have to be captured and stored.

6. <u>Identify the required decision making models</u>.
After the ill-structured problems and relevant data have been targeted for DSS/ES solution, the design engineer must decide what type of model design is necessary to form satisfactory solutions. Most models will incorporate an algorithmic solution structure. For scheduled maintenance, the manipulation of aircraft flight hours will involve simple arithmetic summing operations.

7. <u>Identify the required heuristic rule bases</u>.
Some problem solutions can only be derived through heuristic rule base inferencing vice algorithmic methods. Such rule bases must be identified and captured through knowledge acquisition. Job control number prioritization will require such an effort. What discrepancies should be worked on, for what aircraft and in what order is a daily puzzle that does not lend itself well to mathematical algorithms.

2. System Design and Implementation

An adaptive/prototype design approach is the preferred method for design and implementation of the maintenance control DSS/ES. Representations, Operations, Memory aids and Control mechanisms provide a framework for system construction. The ROMC method helps convert the user's dss into a computerized DSS. This process defines the functional requirements and capabilities of a DSS and facilitates design of the user interface while taking into account appropriate cognitive style.

Traditional "life cycle" design involving lengthy and intensive analysis of user requirements, often falls short

when applied to a DSS/ES. Prototyping is recommended as the appropriate design methodology when building a DSS/ES. The prototype should perform a simple yet needed user function and should accommodate an adaptive design process. A prototype with a specific function permits quick implementation and encourages early user feedback. Early user involvement in the process helps to identify requirements, to shape the system and to reduce user resistance.

3. Evaluation

Because of the numerous intangible benefits associated with a DSS/ES, traditional cost-benefit analysis will not provide justification for a system. Value analysis provides ongoing justification for each module of the system by assigning value to desired capabilities. Testing evaluates whether those capabilities have been provided and identifies new system enhancements. Each new module should be subjected to thorough scrutiny to determine its feasibility, i.e., is it too difficult or costly.

4. Evolution

Adaptive design methods encourage DSS/ES evolution. An adaptive process allows for orderly system expansion by adding functional modules. This allows for earlier deployment of an initial capability with planned expansion as

requirements and funding permit. This approach is recommended for the maintenance control DSS/ES and will provide a means for the system to grow into a powerful, useful tool.

B. RECOMMENDATIONS

The following recommendations are made concerning the development and implementation of a DSS/ES for maintenance control. Suggestions concerning further research are also provided.

1. Maintenance Control DSS/ES

Maintenance control decision makers will benefit from a computerized decision support system that lends structure to ill-structured problems. Using the developed design criteria as a guide, engineers can verify the need, and identify the problems, data, models, and heuristic rule bases required for an effective system.

An initial prototype which aids the decision process in a select area should be implemented early in the development process in order to profit from user insight. An initial system which aids the MCC with flight schedule assignments is recommended. This system will match an aircraft's present capability, based on discrepancies logged against the aircraft, with the requirements of the mission,

as defined in the MESM. Additional information informing the decision maker as to the number of hours remaining before any scheduled maintenance commitment and other pertinent information would be provided.

This system will require a database which contains the MESM mission requirements for aircraft systems and scheduled maintenance commitments per aircraft. Aircraft flight hours flown, data, will have to be collected and entered in the database. A model which matches mission requirements with aircraft capabilities, and compares hours flown with hours remaining will be required.

After successful implementation of the "Aircraft Assignment" model, solutions to other problems can be planned and implemented in an adaptive fashion as separate modules. It is critical that the initial system capture user interest and confidence to ensure system success. Each module should undergo a thorough feasibility study before development and construction costs are incurred.

2. Relevant Additional Research

The development and implementation of a DSS/ES for maintenance control work centers throughout the Navy will be a large undertaking. Costs must be justified, problem areas targeted and a prototype must be developed and tested. The

following are the authors' recommendations for additional research to address these issues.

1. <u>Value analysis research</u>.
   Research must be done to specifically identify the benefits to be gained through the employment of a DSS/ES for value analysis use. Because squadrons have differing missions and operating environments this study should cover a broad spectrum of Navy and Marine Corps activities.

2. <u>Study of the environment</u>.
   An in-depth examination of the maintenance control environment should be conducted to specifically identify problems and critical success factors associated with maintenance control. Again, a broad sampling of Navy and Marine Corps squadrons should be included.

3. <u>Development of a prototype</u>.
   A prototype should be constructed which demonstrates the feasibility and use of such a system in the maintenance control environment. It is feasible and cost effective to have the initial prototype developed and tested as thesis work at the Naval Postgraduate School.

Our analysis suggests that the development and implementation of a computerized decision support system will improve the decision performance of maintenance managers. This performance will result in a higher state of material readiness throughout naval aviation. The design criteria and implementation suggestions provided in this thesis are necessary steps for a successful development.

APPENDIX

GLOSSARY OF ACRONYMS

3-M	Maintenance Material and Management
ADB	Aircraft Discrepancy Book
AD1	Aviation Power Plants Mechanic First Class
AE	Aviation Electrican
AIMD	Aircraft Intermediate Maintenance Department
ALSE	Aviation Life Support Equipment
AMS2	Aviation Structural Mechanic Second Class
AZ	Aviation Administration
CEO	Chief Executive Officer
CNO	Chief of Naval Operations
CSF	Critical Success Factors
DBMS	Database Management System
DDM	Dialog-Database-Model
DSS	Decision Support System (computerized)
dss	decision support system (noncomputerized)
DPF	Development Priority Factor
ES	Expert System
EDP	Electronic Data Processing
FCF	Functional Check Flight

FMC	Fully Mission Capable
JCN	Job Control Number
MCC	Maintenance Contorl Chief
MESM	Mission Essential Support Matrix
MI	Maintenance Instruction
MIS	Maintenance Information System
MMCO	Maintenance Material Control Officer
MO	Maintenance Officer
NALCOMIS	Naval Aviation Logistics Command Management Information System
NAMP	Naval Aviation Maintenance Program
NMC	Not Mission Capable
OPNAVINST	Office of the Chief of Naval Operations Instruction
PDL	Passdown Log
PERT	Program Evaluation and Review Technique
PMCM	Partial Mission Capable Maintenance
PMCS	Partial Mission Capable Supply
PMIC	Periodic Maintenance Information Cards
QA	Quality Assurance
R&D	Research and Development
ROI	Return On Investment
ROMC	Representations, Operations, Memory Aids and Control Mechanisms
SDLM	Standard Depot Level Maintenance

SE	Support Equipment
SOP	Standard Operating Procedures
TD	Technical Directive
VID	Visual Information Display

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